

FORM PTO-1390 (REV 5-93)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 420/50815
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371			U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 10/031438
INTERNATIONAL APPLICATION NO. PCT/DE00/02220	INTERNATIONAL FILING DATE: 6 July 2000 (06.07.00)	PRIORITY DATE CLAIMED 21 July 1999 (21.07.99)	
TITLE OF INVENTION: METHOD, DEVICE AND LASER SYSTEM FOR PRODUCING VIDEO SCREEN HOLOGRAMS AS WELL AS A VIDEO SCREEN HOLOGRAM			
APPLICANT(S) FOR DO/EO/US: Thorsteinn HALLDORSSON			
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:			
<p>1. <input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.</p> <p>2. <input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371</p> <p>3. <input checked="" type="checkbox"/> This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).</p> <p>4. <input checked="" type="checkbox"/> A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.</p> <p>5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2)).</p> <p> a. <input type="checkbox"/> is transmitted herewith (required only if not transmitted by the International Bureau).</p> <p> b. <input checked="" type="checkbox"/> has been transmitted by the International Bureau (FORM PCT/IB/308 attached)</p> <p> c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US)</p> <p>6. <input checked="" type="checkbox"/> A translation of the International Application into English (35 U.S.C. 371(c)(2)).</p> <p>7. <input type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).</p> <p> a. <input type="checkbox"/> are transmitted herewith (required only if not transmitted by the International Bureau).</p> <p> b. <input type="checkbox"/> have been transmitted by the International Bureau.</p> <p> c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired.</p> <p> d. <input type="checkbox"/> have not been made and will not be made.</p> <p>8. <input type="checkbox"/> A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).</p> <p>9. <input type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).</p> <p>10. <input type="checkbox"/> A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).</p> <p>Item 11. to 16. below concern other document(s) or information included:</p> <p>11. <input checked="" type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98.</p> <p>12. <input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.</p> <p>13. <input checked="" type="checkbox"/> A FIRST preliminary amendment.</p> <p> <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment.</p> <p>14. <input checked="" type="checkbox"/> A substitute specification.</p> <p>15. <input type="checkbox"/> A change of power of attorney and/or address letter.</p> <p>16. <input checked="" type="checkbox"/> Other items or information: International Preliminary Examination Report and translation of printed pages attached thereto with Transmittal of IPER; Five (5) sheets of drawings showing Figures 1-6; Form PCT/IB/308; Form PCT/IB/306 - Notification of the recording of a Change; Form PCT/IB/301 - Notification of Receipt of Record Copy; First page of Published International Application; Application Data Sheet</p>			

U.S. APPLICATION NO. (if known, see 37 CFR 1.53) 10/031438		INTERNATIONAL APPLICATION NO. PCT/DE00/02220		ATTORNEY'S DOCKET NUMBER 420/50815	
17. [X] The following fees are submitted: Basic National Fee (37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO \$890.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) \$690.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) \$710.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$1000.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) \$100.00 ENTER APPROPRIATE BASIC FEE AMOUNT = \$				CALCULATIONS	
				PTO USE ONLY	
				\$ 890.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than [] 20 [X] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$ 130.00	
Claims	Number Filed	Number Extra	Rate		
Total Claims	24-20=	4	X \$18.00	\$ 72.00	
Independent Claims	8-3=	5	X \$84.00	\$ 420.00	
Multiple dependent claims(s) (if applicable)			+ \$270.00	\$	
TOTAL OF ABOVE CALCULATIONS =				\$ 622.00	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				\$	
SUBTOTAL =				\$ 1,512.00	
Processing fee of \$130.00 for furnishing the English translation later than [] 20 [] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				\$	
TOTAL NATIONAL FEE =				\$ 1,512.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28,3.31). \$40.00 per property +				\$	
TOTAL FEE ENCLOSED =				\$ 1,512.00	
				Amount to be: \$	
				refunded	
				charged	\$

- a. [X] A check in the amount of \$ 1,512.00 to cover the above fees is enclosed.
- b. [] Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.
- c. [X] The Commissioner is hereby authorized to charge any additional fees, which may be required, or credit any overpayment to Deposit Account No. 05-1323. (Attorney Docket No. 420/50815.) A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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Attorney Docket: 420/50815
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: THORSTEINN HALLDORSSON
Serial No.: NOT YET ASSIGNED PCT No.: PCT/DE00/0220
Filed: JANUARY 22, 2002
Title: METHOD, DEVICE AND LASER SYSTEM FOR PRODUCING
SCREEN HOLOGRAMS, AS WELL AS A VIDEO SCREEN
HOLOGRAM

PRELIMINARY AMENDMENT

Box PCT
Commissioner for Patents
Washington, D.C. 20231

January 22, 2002

Sir:

Please enter the following amendments to the specification and claims, as amended by way of Annexes to the International Preliminary Examination Report for PCT/DE00/02220, prior to the examination of the application during the U.S. National Phase.

IN THE SPECIFICATION:

Submitted herewith is a substitute specification and marked-up copy thereof which includes the changes made by way of the Annexes to the International Preliminary Examination Report.

IN THE CLAIMS:

Please cancel all of the claims presently in the application and substitute new Claims 23-46 as follows:

23. (New) A method of producing a video screen hologram in which a real video screen is illuminated by narrowband light to generate a hologram of the real video screen, a plurality of individual recordings being made, in each case only a partial area of the real video screen being illuminated, so that a video screen hologram of the entire video screen is obtained by a composition of the individual recordings, wherein illumination of the video screen is performed using a scanning pulsed laser beam.

24. (New) The method according to Claim 23, wherein the pulse duration is dimensioned such that the movement of the laser beam over the video screen has substantially no effect on interference of the light waves in the hologram.

25. (New) The method according to Claim 23, wherein the partial areas of the video screen have a size that corresponds to image pixels.

26. (New) The method according to Claim 23, wherein the lumination takes place by means of a pulsed diode-pumped solid-state continuous-wave laser.

27. (New) The method according to Claim 23, wherein a frequency conversion takes place in one or several of the wavelength ranges red, green, blue.

28. (New) The method according to Claim 23, wherein a contact hologram or a video screen plane hologram is generated.

29. (New) The method according to Claim 24, wherein a contact hologram or a video screen hologram is produced.

30. (New) The method according to Claim 23, wherein a transmission hologram or a reflection hologram is produced.

31. (New) The method according to Claim 23, wherein laser beams of a coherence length are generated which is greater than a difference between light paths of the object beam and the reference beam.

32. (New) The method according to Claim 24, wherein a scanning rate and a pulse duration of scanning pulsed laser are mutually coordinated such that the movement of the laser beam during a pulse is smaller than 1/10 of the wavelength.

33. (New) The method according to Claim 23, wherein a repeated scanning of the video screen surface takes place by means of a respectively phase-shifted laser beam.

34. (New) The method according to Claim 23, wherein distribution of the lumination in the hologram is measured to correct lumination in a subsequent lumination cycle.

35. (New) The method according to Claim 23, wherein plural luminations are carried out with mutually perpendicularly polarized energy beams to produce two mutually independent screen images in the hologram.

36. (New) A device for producing a video screen hologram, having a narrowband light source for illuminating a real video screen, wherein:

the light source is arranged such that the light emanating from the video screen is superimposed with a reference beam in order to produce a hologram of the video screen;

a scanning device is provided for guiding light radiation emanating from the light source over the video screen; and

the light source generates pulsed light radiation.

37. (New) The device according to Claim 36, wherein the light source simultaneously generates red, green and blue laser radiation.

38. (New) The device according to Claim 36, wherein the light source comprises a laser system, having a laser beam source having a pulsed q-switched single-frequency IR-laser oscillator, a frequency conversion device, and an optical parametric oscillator.

39. (New) The device according to Claim 38, wherein the laser beam source comprises a laser amplifier connected behind the q-switched single-frequency IR laser oscillator.

40. (New) A video screen hologram comprising a holographic recording material in which a real video screen is stored as a hologram, wherein:

the video screen hologram comprises a plurality of individual recordings, in each of which a partial area of the real video screen is imaged as a hologram, an entire image of the whole video screen resulting from assembled or superimposed individual recordings; and

the individual recordings are generated by illuminating the video screen by means of a scanning pulsed laser beam.

41. (New) A laser system for producing video screen holograms by means of RGB beams, having a laser beam source for generating laser radiation, a frequency conversion device, and an optical parametric oscillator, wherein the laser beam source comprises a pulsed q-switched single-frequency IR laser oscillator.

42. (New) The laser system according to claim 41, wherein the laser beam source comprises a laser amplifier connected behind a q-switched single-frequency IR laser oscillator.

43. (New) A video screen hologram comprising a holographic recording material in which an image of a real video screen is stored as a hologram, wherein:

the video screen hologram comprises a plurality of individual recordings, each of which contains a holographic image of a partial area of the real video screen; and

an entire image of the whole video screen is formed from assembled or superimposed individual recordings.

44. (New) A method of generating a video screen hologram, comprising:

illuminating a real video screen with narrow band light by successively illuminating partial areas of the real video screen;

recording a plurality of individual holographic images in a recording medium, each of which covers only a single partial area of the real video screen, said individual holographic images collectively covering the entire real video screen; and

forming a composite of said individually recorded holographic images to generate a video screen hologram of the entire real video screen;

wherein illumination of the video screen is performed using a scanning pulsed laser beam.

45. (New) A device for recording a video screen hologram in a recording medium, comprising:

a laser beam source comprising a q-switched single-frequency IR laser oscillator for generating laser radiation; and

a scanning device for causing laser radiation from said laser beam source to scan a surface of a real video screen, sequentially illuminating successive partial areas thereof, whereby a plurality of holographic images are formed in said recording medium, each covering a single one of said partial images.

46. (New) Apparatus for producing a video screen hologram, comprising:

a narrowband light source arranged to illuminate a real video screen, such that light emanating from said video screen is superimposed with a reference beam so as to generate a hologram of the video screen; and

a scanning device for guiding light radiation from the light source over a surface of the video screen;

wherein, the light source generates pulsed light radiation.

IN THE ABSTRACT:

Please substitute the new Abstract of the Disclosure submitted herewith on a separate page for the original Abstract presently in the application.

REMARKS

Entry of the amendments to the specification and claims, as amended by way of Annexes to the International Preliminary Examination Report for PCT/DE00/02220, before examination of the application in the U.S. National Phase is respectfully requested.

If there are any questions regarding this amendment or the application in general, a telephone call to the undersigned would be appreciated since this should expedite the prosecution of the application for all concerned.

If necessary to effect a timely response, this paper should be considered as a petition for an Extension of Time sufficient to effect a timely response, and please charge any deficiency in fees or credit any overpayments to Deposit Account No. 05-1323 (Docket #420/50815).

Respectfully submitted,



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ABSTRACT OF THE DISCLOSURE

In a method of producing video screen holograms, a real video screen is illuminated by means of a narrowband light for producing a hologram of the real video screen. A plurality of individual recordings is carried out, each covering only a partial area of the real video screen being imaged in the hologram. The individual recordings take place, for example, by means of a scanning pulsed laser beam. The individual recordings are assembled to form the video screen hologram of the entire video screen. A recording device for this purpose comprises a scanning device for guiding the light radiation over the video screen and a light source which generates pulsed light radiation. The light source is, for example, a laser system with a pulsed q-switched oscillator and with an optical parametric oscillator.

METHOD, DEVICE AND LASER SYSTEM FOR PRODUCING VIDEO
SCREEN HOLOGRAMS AS WELL AS A VIDEO SCREEN HOLOGRAM

The invention relates to a method, a device and a laser system for producing video screen holograms as well as to a video screen hologram according to the preambles of Claims 1, 16, 19 and 21.

Video screen holograms, which are produced as holographic images of real white video screens or video projection screens and are recorded by means of lasers in the primary colors red, green and blue (rgb), have the advantage that they are effective only within a narrow spectral range about the recording wavelength and simultaneously only within a very limited projection angle about the direction of incidence of the reference beam during the preceding hologram recording. The method of operation of such screens or holographic video screens is described in detail in German Patent Applications No. 19700162.9 and No. 19703592.2.

As the light sources for the projection, rgb lasers in the continuous wave mode and in the pulsed mode as well as rgb light-emitting diodes can mainly be used. The image build-up can optionally be implemented by the serial scanning of a collimated laser beam or by the imaging of an image modulator

in the expanded beam of a laser or a light-emitting diode onto the screen. Holographic video screens can be produced for the front projection as well as for the rear projection. Because of their wavelength selectivity and directional selectivity, bright and high-contrast images of a high color fidelity can be projected onto video screen holograms even in a daylight environment. The projector with the narrowband light sources is placed at the beam origin of the divergent reference beam.

Only from there will the projection light be efficiently diffracted out of the hologram toward the viewer. In this case, for example, the diffuse broadband ambient light can, in an unhindered manner, traverse the video screen hologram from all other directions of incidence.

For the reproduction or the projection of images onto video screen holograms, for example, rgb lasers are used, as described in "RBG Optical Parametric Oscillator Source", K. Snell et al., Aerosense 99, and in German Patent Documents DE 195 04 047 and DE 44 32 029.

The possible applications of video screen holograms extend over the wide field of small displays, for example, for a single person in vehicles and airplanes or at office workstations, to large-surface screens for several viewers at events.

The smaller displays can be recorded by means of frequency-stable rgb continuous-wave lasers. In this case, the high requirements with respect to the stability of the laser and of the course of the beam and the connected high expenditures are disadvantageous and result in high cost.

An image representation on large video screen holograms which is independent of the ambient light would be very attractive, for example, for many different applications in the home and the office, for television, computers and electronic cinema and for projections in lecture halls, movie theaters and open-air theaters. However, the production of larger video screens, for example, of the size of typewriter paper (DIN A4) or larger, presents considerable technical difficulties.

First, the output power of the strongest continuous-wave lasers for hologram recordings is currently limited to only a few watts, which, when luminating the particularly suitable silver halide and photo polymer materials, starting at a size of 1 m^2 , requires a lumination time of tens of minutes. For these long lumination times, the requirements with respect to the mechanical and thermal stability of the material, with respect to the optical components of the beam path and with

respect to the frequency stability of the laser are particularly high.

Second, the object beam and reference beam when recording the hologram must be expanded at the expense of the light output over the size of the video screen and of the hologram, because the radial intensity distribution is not constant over the laser beam but follows a normal distribution which requires a considerable widening in order to achieve a lighting which is as homogeneous as possible over the surface of the holograms. When, for creating a large video screen hologram, several video screen holograms are joined together, the intensity drop toward the edges of the individual luminated holograms is particularly disturbing because then a periodic shadow pattern will run through the entire video screen during the projection.

Third, the luminating of the three rgb colors of three lasers into the same hologram results in difficulties because a uniform luminating of all three lasers over a larger surface can hardly be achieved. Because the wavelengths of the lasers are clearly different, differences occur in the beam transmission by refraction, diffraction and scattering at different points of the entire beam path, which leads to a nonuniform color display and is difficult to eliminate in the

case of an imaging over an extensive surface.

It is therefore an object of the present invention to provide a method, a device and a laser system which permits the simple production of high-quality small as well as large-surface video screen holograms. Furthermore, a video screen hologram is to be created which can also be implemented in a large-surface manner without any reduction of the quality of the image during the projection.

This object is achieved by means of the method and the device for producing video screen holograms according to Claims 1 or 16, by the laser system according to Claim 19 as well as by the video screen hologram according to Claim 21. Additional advantageous characteristics, aspects and details of the invention are contained in the dependent claims, the description and the drawings.

In the case of the method according to the invention, a real video screen is illuminated by means of a narrowband light in order to produce a hologram of the real video screen, a large number of individual recordings being made in the case of which only one partial area respectively of the real video screen is illuminated, so that the video screen hologram of the entire video screen is obtained by the composition and/or

superimposing of the individual recordings. As a result, only very brief luminating times are possible so that disturbances during the lumination, for example, by shocks or other instabilities are avoided. Furthermore, there is no occurrence of intensity reductions at the edge or of periodic shadow patterns. A uniform color display becomes possible on large surfaces.

Advantageously, the illumination takes place by means of a scanning pulsed laser beam. The pulse duration is, for example, dimensioned such that the movement of the laser beam over the video screen has no influence on the interference of the light waves in the hologram. The recorded partial areas of the video screen preferably correspond to the size of image pixels or are larger. In particular, the lumination can take place by means of a pulsed diode-pumped solid-state continuous-wave laser.

A frequency conversion preferably takes place in one or several of the wavelength ranges red, green, blue. For example, a contact hologram or a video screen plane hologram is produced. A transmission hologram or a reflection hologram may also be produced. Laser beams are preferably generated with a coherence length which is greater than the difference of the light paths between the object beam and the reference

beam. The scanning rate and the pulse duration are, for example, coordinated with one another such that the movement of the laser beam during a pulse is less than $1/10$ of the wavelength.

Preferably, a repeated scanning of the video screen surface takes place by means of a respectively phase-shifted laser beam. The distribution of the lumination can be measured in order to correct the lumination during a subsequent lumination cycle. Several luminations may also be carried out by means of light rays or laser beams which are polarized perpendicular to one another in order to produce two mutually independent screen images in the hologram. Furthermore, several luminations with changed recording parameters can be carried out, for example, a changed site of the real video screen or a changed place of origin of the reference beam. The lumination preferably takes place simultaneously by means of light rays or laser beams of the primary colors red, green, blue, which are coaxially adjusted on a beam axis.

The device according to the invention for producing video screen holograms has a narrow-band light source for illuminating a real video screen, which light source is, for example, arranged such that the light emanating from the video

screen is superimposed with respect to a reference beam in order to produce a hologram of the video screen, in which case, furthermore, a scanning device is provided for guiding the light radiation emanating from the light source over the video screen, the light source generating a pulsed light radiation. As a result, high-quality large-surface video screen holograms can also be produced in a simple manner.

The light source preferably simultaneously generates a red, green and blue laser radiation. The light source comprises particularly a laser system which will be described in the following.

The laser system according to the invention for producing RGB rays is suitable particularly for the generating of video screen holograms and comprises: A laser beam source for generating laser radiation, a frequency conversion device, and an optical-parametric oscillator, the laser beam source comprising a pulsed q-switched laser oscillator.

By means of this laser system, large-surface video screen holograms for a color projection with a high image quality can be produced in a simple manner.

The q-switched laser oscillator is preferably a single-

frequency IR oscillator. The laser beam source has, for example, a laser amplifier which is connected behind the q-switched laser oscillator. The video screen hologram according to the invention has a holographic recording material in which a real video screen is stored as a hologram, the video screen hologram containing a large number of individual recordings in which, in each case, a partial area of the real video screen is imaged as a hologram, the entire image of the video screen resulting from assembled and/or superimposed individual recordings. This results in a high-quality image reproduction, even in the case of a large-surface implementation of the video screen hologram.

The video screen hologram is preferably produced according to the method of the invention.

The invention will be described in the following in the manner of an example by means of the figures.

Figure 1 is a schematic lateral view of an arrangement for recording a reflection video screen image hologram as a contact hologram;

Figure 2 is a top view of the arrangement according to Figure 1;

Figure 3 is a schematic view of an arrangement for recording a transmission video screen hologram as a contact hologram;

Figure 4 is a view of an arrangement for recording a video screen reflection hologram for a front projection;

Figure 5 is a view of an arrangement for recording a transmission video screen hologram for a rear projection as an image plane hologram; and

Figure 6 is a schematic view of a laser system according to the invention.

Figure 1 is a schematic lateral view of the recording of a reflection hologram of a video screen as a contact hologram for a later front projection. A holographic recording material 12 is in contact with a video screen 11. A laser beam bundle 13 from a rapidly pulsed laser 16 is scanned by means of scanners 14 and 15 over the recording material 12 in two axis directions x and y in a surface-covering manner, for example, by means of a circular-shaped laser beam spot.

Figure 2 is a top view of the holographic recording material 12. The laser beam 13 successively illuminates a partial area

11a of the recording material 12 and of the video screen 11 situated behind the latter. Differently shaped laser spots, such as a rectangle, may also be used. A portion of the impinging laser radiation 13 is allowed by the hologram or the recording material 12 to pass through and impinges on the real video screen 11 which scatters radiation 17 as object light waves back into the hologram 12. There, the object light waves again impinge on the incident beam 13 and, together with its waves, form holographic interference patterns which are stored by the luminating process as a hologram in the recording material 12. Many different scanning figures can be used, such as raster scans, sinusoidal scans or spiral scans.

Thus, the video screen hologram is not recorded as a whole in one piece as an image of the real video screen 11 but in a very large number of individual recordings in which in each case only small portions 11a of the real video screen 11 are illuminated. The entire image of the video screen 11 will then be obtained as a composition or superimposition of the large number of individual recordings, for example, in the manner of image pixels.

The produced video screen hologram is constructed as a contact hologram or as a so-called image plane hologram, in which the projected image when displayed appears in the

hologram plane. By luminating screens in the primary colors red, green and blue into the same hologram layer 12 or into three layers laminated onto one another, colored images can later also be projected onto the holographic screen.

Contact holograms have the advantage of a simple optical construction during the recording. As illustrated in Figure 1, the hologram is therefore placed in contact onto the real video screen 11, for example, a reflecting scattering lens or transmitting obscured glass and is luminated together with the reference beam without any additional object illuminating. During the projection, the angle of the backscattered projection light from the hologram 12 in the direction of the viewer is the same as that of the real video screen with respect to the recording light beam 13.

The invention is based on the fact that the holographic video screen or the hologram 12 must reflect the optical characteristics of the image pixels, that is, the brightness (half-tone), the color, the polarization and the angle of radiation only individually for each pixel from the screen. An optical linking between adjacent pixels does not exist, and a video screen as a contact or image plane hologram has only a two-dimensional structure. So that the hologram 12 can reflect this method of operation of a flat video screen in the

hologram plane, it is not absolutely necessary to record the real video screen 11 in a single lumination over an extended hologram surface, as takes place in the case of holograms of three-dimensional objects, but the video screen may be constructed as an assembled film or a film constructed in a mosaic-type of separate individual recordings of partial areas 11a of a video screen. These partial areas 11a may therefore be reduced to the size of an individual image pixel.

The holographic video screen is recorded by luminating the real larger video screen 11 with a rapidly pulsed laser beam 13 which is scanned without gaps over the entire surface.

So that the movement of the beam 13 over the screen 11 or over the recording material 12 has no influence on the interference of the light waves in the hologram 12, it is ensured that, on the one hand, the pulse duration of the laser 16 is sufficiently short, and that, on the other hand, the coherence length of the laser light is sufficient for the forming of the interferences. In order to achieve a particularly economical production of the holographic screen, the pulse repetition frequency of the laser 16 and its median power is sufficiently high so that a short luminating time is achieved.

Suitable lasers for this type of holographic lumination

are, for example, high-power, rapidly pulsed, diode-pumped infrared solid-state continuous-wave lasers with only a single longitudinal mode whose radiation is displaced by frequency conversion into the red, green and blue wavelength range. The scanning of the video screen surface can take place by means of commercially available laser beam scanners.

The partial holograms 11a are selected at least so large that no disturbances occur, such as a reduction of contrast, a color distortion and a reduction of the image resolution in the later image reproduction by light diffraction or a fine structure of the holograms itself. Such disturbances are not expected if the partial holograms 11a are larger than the image pixels of the projection. On the other hand, the size and the shape of the partial hologram 11a and the scanning rate can be selected such that, by means of the defined operating parameters of the recording laser, such as the median power and the pulse repetition frequency, an optimal irradiation and a homogeneous illumination of the hologram 12 is achieved without reducing the efficiency of the recording simultaneously by the movement of the scanning beam 13.

In general, for the recording of object holograms, the object itself must be illuminated by means of an object beam and the hologram must be illuminated by means of a reference

beam. The light scattered by the object is then superimposed in the hologram film with respect to the reference beam. In the case of the pulsed recording illustrated here, in which only a portion 11a of the real video screen 1 is illuminated as the object and simultaneously a portion of the hologram 12 is illuminated directly by means of the pulsed reference beam 13, the luminations are implemented in a synchronously superimposed manner. This can easily be implemented by means of contact holograms, in the case of which the hologram film 12 is placed directly on the real video screen 11 and the reference beam 13 is used for illuminating the hologram 12 and for illuminating the video screen 11.

In the case of image plane holograms, the video screen is imaged by means of a lens into the hologram. So that the partial illumination of the video screen with the object beam and the hologram with the reference beam mutually overlap, the two scanning beams must be mutually synchronized during their movement such that the imaged spot of the video screen in the hologram and the spot of the reference beam will in each case be congruent.

During the lumination, the light waves in the object beam and the reference beam must be coherently imposed on one another in the hologram. This means that the coherence length

of the used illumination laser 16 has to be at least as large as or larger than the difference of the light paths between the waves of the object beam and the reference beam which originate from a common beam, until they meet again in the hologram 12. Within the scope of the invention, this demand can be met by a corresponding design of the beam guidance and the build-ups of the holograms with respect to the coherence length of the available lasers.

The movement of the interfering waves in the hologram by the scanning beams (object beam and reference beam) during the pulse duration with respect to one another and with respect to the hologram film amounts to no more than fractions of the wavelength ($<\lambda/10$). This condition is met by a corresponding adjustment of the scanning rate in relationship to the pulse duration of the laser. In the case of a pulse duration of 10 ns and a scanning rate of 5 m/sec, the movement of the beam is, for example, 50 nm, which corresponds to approximately $\lambda/10$.

During the scanning with a pulsed radiation at a constant power from pulse to pulse, a large hologram surface can be covered with a uniform average intensity distribution, but the lumination, that is, the light intensity times the time, depending on the ratio of the scanning rate to the pulse

repetition frequency of the beam with the Gaussian intensity profile, will be periodically modulated over the whole surface along the scanning sweep. The invention therefore also provides that this periodic local non-uniformity of the illumination as well as inhomogeneities in the hologram thickness, for example, in the case of a mosaic-type laying of several holograms side-by-side, are compensated by a repeated scanning of the same surface by means of a phase-shifted scanning beam or by controlling the pulsed power. Here, the invention partly utilizes the characteristic of hologram recordings that several object luminations can be stored in an overlapping manner and independently of one another in a single hologram.

So that this lumination process can take place automatically, in an embodiment of the invention which is not shown, the distribution of the lumination is monitored by a calibrated backscatter sensor which is arranged in the beam path of the illumination laser coaxially to the pulsed lumination beam. As an alternative, monitoring cameras may continuously measure the laser illumination over the entire hologram surface. The thus obtained lumination pattern can be stored by a microprocessor or computer and can be used during subsequent repeated scanning cycles over the entire hologram surface by controlling the laser light intensity and surface

distribution of the scanning figure for the subsequent correction of the lumination of the preceding lumination patterns.

After the development process, the optical characteristics of the video screen are stored in the hologram 12. Preferably, so-called thick holograms (10-20 μm) are used, for example, consisting of photopolymer, dichromate gelatin or silver halide materials. In comparison to thin holograms, thick holograms have the advantage that they particularly selectively diffract out light with the same wavelength as during the recording, specifically only when the angle of incidence of the reconstruction beam is the same as the angle of incidence of the reference beam during the recording.

The optimal accumulated lumination of the holograms differs for each material and for each wavelength. For photopolymer materials, for example, it is at approximately 25 mJ/cm^2 ; that is, for the lumination of 1 m^2 with a laser 1 W of median power, 250 seconds or approximately 4 minutes are required. In the case of silver halide films, a lumination of only approximately 0.5 mJ/cm^2 , whereby the lumination time can be correspondingly shortened. Image plane holograms are recordings of screens imaged by means of lenses or mirrors,

which screens are situated in the hologram plane. The angle of radiation of these holograms can be considerably narrowed by the imaging geometry, with a corresponding increase of the brightness of the image, which is very advantageous for many applications.

Figure 3 illustrates a recording of a contact hologram of a video screen 31 as a transmission hologram 32. In this case, it is necessary that a reference bundle of beams 33, whose beam path coincides with the projection beam during the later image reproduction, impinges as a convergent partial beam bundle of a pulsed laser 39 on the hologram 32. The interference structures which then form in the hologram 32 as the result of the superimposition of scattered light 30 from the screen on the reference bundle 33 of beams, will then correspond to an image reproduction in a rear projection from the intersection or projection point 36, that is, the lengthening of the beam bundle 33. During the projection, the viewer will then stand opposite the later projection point 36 on the opposite side of the hologram 12. The generating of a convergent bundle of beams from a two-axis scanner 34 and 35 can most easily be implemented by way of a mirror 37 of a long focal length which images the source point of the scanner 38 in the intersecting point 36. The hologram 32 and the real video screen 31 are then placed in a sectional plane of the

beam path of the partial beam bundle 33.

Figure 4 illustrates a recording of a transmission hologram as an image plane hologram for the rear projection. Here, a real video screen 41 is imaged by means of a lens 46 on a hologram 42. Simultaneously, a reference beam bundle 43 impinges from the other side on the hologram 42. The two scanners with the x-y scanner mirrors 57 and 58 or 57' and 58' are synchronized such that the two illumination spots of the reference beam bundle 43 and of the illuminated surface 40 of the real screen in the hologram 41 are synchronously superimposed. The illumination beams for the real screen 42 and for the reference bundle 43 of beams are separated and deflected by means of separator mirrors 44 and deflecting mirrors 44' from the common laser 49.

Figure 5 illustrates a recording of an image plane hologram as a reflection hologram for the later front projection. In this case, a real screen 51 is imaged in a hologram plane 52 by means of a lens 56, and the image is synchronously superimposed there with a reference bundle 53 of beams. By means of a separator mirror 54, a portion of the reference bundle 53 of beams can be used for illuminating the real screen 51. Additional auxiliary mirrors are required for compensating the space reflection of the lens 56, which is

illustrated here for the one space plane on the example of the auxiliary mirror 55. For the simultaneous scanning of the screen 51 and the hologram 52, only one pair of scanner mirrors 57 and 58 is used here in front of the pulsed laser 59.

In order to facilitate the recording of three-color or multicolor screens, for example, of the rgb colors, the beams of three rgb lasers or of one laser with a three-color rgb emission are coaxially adjusted with respect to an identical beam axis. During a joint scanning and luminating of the screen and of the hologram with the reference beam, the three colors are simultaneously on the real video screen. The reference beam also represents a superimposition of three rgb partial beams.

This simultaneous recording of all three rgb colors in the same hologram naturally requires that the hologram material is photosensitive to all colors. However, this also applies to a number of photopolymers and silver halide films as well as to individual dichromate gelatins.

For recording the video screen holograms described here with a rapidly pulsed rgb illumination, modern diode-pumped, q-switched infrared solid-state lasers are used with an

emission in only one longitudinal resonator mode. The lasers are adjusted to the rgb emission at the suitable rgb wavelengths by a classical frequency conversion, such as frequency doubling, optically parametric processes and summation and difference frequency formation, in various non-linear crystals.

Separate lasers can be used for the individual colors, but it is more advantageous to use lasers which have a single joint q-switched laser oscillator. The lasers of joint amplifier stages on the output side and a joint optical-parametric oscillator which splits the fundamental wave of the laser or its frequency-doubling wave into two partial waves of a longer wavelength (idler and signal wave). A subsequent beam separation is used for separating the primary radiation into different beam branches, where different further frequency conversions take place, such as frequency doubling, frequency summation and difference formation for producing the individual colors.

A significant advantage of such a joint primary laser is the fact that the emission of all three rgb color branches takes place completely synchronously with the same pulse repetition frequency, in a solid phase and with a comparable spectral width, coherence length and beam divergence. This

permits a joint recording of the video screen holograms simultaneously in all colors.

RGB lasers, which are based on this basic concept of a joint primary laser with a subsequent frequency conversion in passive non-linear crystals to the three rgb colors, are described, for example, in the above-mentioned German Patent Document DE 195 04 047, "Laser System for Color Image Projection", and in German Patent Document DE 44 32, 029, "Laser-Supported Color Image Display and Projection Device". The diode-pumped solid-state lasers described there are operated in the mode-locked continuous-wave mode. However, with respect to the recording of video screen holograms, they have the disadvantage that they emit a wide frequency spectrum of individual longitudinal modes, that is, of a short coherence length in the primary emission as well as after the frequency conversion.

Figure 6 illustrates a laser according to the invention which is particularly suitable for the above-described pulsed video screen hologram recordings. In this case, instead of a mode-locked laser, a rapidly pulsed q-switched single-frequency IR oscillator 61 of an Nd laser, such as Nd:YLF, Nd:YAG or Nd:YVO, is provided; that is, the oscillator 61 has a single longitudinal mode. The power amplification of the

pulses takes place in a solid-state laser amplifier 62 of the same materials. An optical parametric oscillator 65 is provided for a subsequent frequency splitting. This oscillator can be adjusted in its wavelength by way of the temperature of the non-linear material and/or the adjustment of the axis angle in the beam path. As a result, the wavelength of the effective rgb radiation can also be adjusted during the subsequent frequency conversion. This is advantageous for precisely adapting the recording wavelength to the later reproduction wavelength. A frequency doubling and summation frequency formation also takes place. The oscillator 61, is a q-switched Nd:YAG in the longitudinal single-mode operation. The laser amplifier 62 is an Nd:YAG or Nd:YVO amplifier chain. Furthermore, a frequency doubler crystal 63 is provided as well as beam separators 64, 64' for separating the fundamental radiation of the primary laser $\lambda_1=1.06 \mu\text{m}$ from the frequency-doubled green radiation $\lambda_1=0.53 \mu\text{m}$. The optical parametric oscillator 65 is pumped by means of the green beam λ_1 and adjusted such that it generates two signal and idler beams (λ_s and λ_1 respectively), which have a suitable wavelength for a subsequent summation frequency formation in summation frequency generators 66, 67. In this case, the wavelengths λ_s and λ_1 are selected such that the summation frequency formation with the beams of the fundamental wavelength of the laser $\lambda_1 = 1.06 \mu\text{m}$ (or $1.04 \mu\text{m}$),

which remains after the frequency doubling, results in suitable wavelengths of red and blue. In contrast, the color green is taken over as part of the frequency-doubled radiation of the primary laser by way of splitting by the simple beam separator 64, 64'.

The suggested rapidly pulsed q-switched laser 61 is a continuous-wave laser oscillator with only one longitudinal fundamental mode which is operated in a pulsed operation of the resonator. A laser of this type is, for example, a diode-pumped solid-matter microchip laser, such as the Nd:YAG at a laser wavelength $1.06\text{ }\mu\text{m}$ with such a short resonator that it starts lasing only on a longitudinal mode. By means of an internal passive quality switch, for example, made from the known Cr^{4+} :YAG material, the resonator can be adjusted by the doping with Cr^{4+} ions, for example, to 20 kHz pulse frequency with a pulse duration of 10 ns.

The IR-emission of the laser 61 is now be highly amplified in the amplifier 62 which follows; for example, by means of the crystal Nd:YAG or Nd:YVO, by a factor 10-100, without creating interfering higher longitudinal modes, also while maintaining the good beaming quality of the oscillator.

After the amplification, the pulsed beam is then still frequency-doubled to the desired green wavelength 532 nm,

which occurs here in a KTP crystal 63. After the frequency doubling, which takes place here with an efficiency of approximately 30%, a portion of the primary radiation with a wavelength of 1.06 μm remains for a further use in the subsequent stages.

A second possibility is the use of passively quality-switched Nd:YAG ring lasers with the same Cr^{4+} YAG quality switch, a similar pulse repetition frequency, but a better frequency stability and a higher median power. By means of subsequent amplifier stages as in the previous case, a median power of 10-39 W can be generated in a longitudinal mode.

One possibility is the use of a laser actively quality switched by means of an acoustic-optical switch with an internal standard for adjusting a single-mode operation, which, however, requires slightly higher expenditures in comparison to the second process.

Q-switched continuous-wave lasers of the type described here have a pulse repetition frequency of 10-20 kHz, a pulse width of 5-20 ns and a frequency bandwidth of the laser emission below 100 MHz. They can be designed such by means of an amplifier stage that, after the frequency doubling 1 W green emission is created, and by means of two or three

stages, up to 10 W green radiation is generated and 30 W infrared radiation is generated in the device. After the conversion in the optical parametric oscillator 65 and a further frequency doubling or summation frequency formation, all rgb beams can then be produced with a median power of several watt. A significant advantage of this concept is also that the colors blue and red can be continuously displaced by the adjustment of the wavelengths of the idler and signal wavelength λ_s , λ_i in the optical parametric oscillator 65 for the adaptation to the wavelength of the later image projection lasers.

By means of the characteristic laser data, such laser systems are particularly well suitable for the recording of the video screen holograms. If, for example, the pulse duration of the laser amounts to 10 ns and the scanning rate amounts to 5 m/sec, during this pulse duration, the beam moves laterally by 5×10^{-8} m during this pulse duration, which corresponds to 1/10 of the wavelength at, for example, 500 nm.

This small displacement has no noticeable influence on the quality of the interference pattern in the hologram. If the pulse frequency were, for example, 20 kHz, the beam would move from pulse to pulse at this scanning rate by 1/4 mm. The coherence length of a $\Delta t = 10$ ns single-mode pulse amounts to approximately $\Delta t \cdot c = 3$ m, wherein c is the speed of light.

The difference of the travelling paths of the object and reference beam must not exceed this value, which can easily be observed in the case of all suggested build-ups of the holograms.

Therefore, video screen holograms can be designed either for a front projection as a reflection hologram or for a rear projection as a transmission hologram. Either the recording in the contact process with the real video screen, or as an image plane hologram, that is, after an imaging of the video screen on the hologram, as illustrated above, are suitable for both processes. In all cases, the object beam and the reference beam are moved synchronously over the hologram.

Only light sources with an identical linear polarization can interfere with one another and be stored as a holographic image of screens in a hologram; that is, only light waves of an identical linear polarization in the reference beam and the object beam can contribute to generating the image of the video screen. Therefore, the lasers used for the recording of the holograms are preferably polarized in a strictly linear manner in order to ensure the efficiency and the homogeneity of the illumination over the entire hologram surface. Since most lasers with a good beaming quality are strictly linearly polarized from the start, this does not cause any limitation

of the recording technique.

For the recording of video screens for the stereoscopic image reproduction, video screen materials are used which depolarize an impinging linearly polarized light beam by backscattering or by forward scattering. This applies to many projection screen materials for the rear projection with a good fine roughness of the surface or a slight volume scattering and to almost all projection screens with a high volume scattering for rear projections. Since the reference beam also has a strict polarization direction of the laser, when a real video screen is recorded, this polarization direction is maintained in the hologram. If now two recordings are successively made of the same screen, in which case the polarization direction of the reference beam is rotated from one to the other by 90° , two independent screen images are created in the same video screen hologram, each being effective only with respect to a projection beam with a defined polarization direction. Both screen images affect mutually orthogonal polarized projection beams. Thus, also prerequisites are met for the projection of mutually orthogonally polarized stereo images and their stereoscopic viewing by means of polarization glasses.

The switch-over of the polarization by 90° in the reference beam can be carried out in a very simple manner by rotating a $\lambda/2$ -plate in the beam path behind the outlet aperture of a strictly linearly polarized illumination laser.

If several video screen recordings are made of the same screen successively into the same hologram while the site of the whole screen or of the place of origin of the reference beam are changed, the interfering speckle images are superimposed coherently with a statistical size distribution.

Together, they represent a new virtual screen after the luminations, which screen has a significantly higher fine structure than the real original screen. This results in a displacement of the entire appearance image toward larger speckles which then, during the subsequent image reproduction, can be eliminated more easily by a slight local or time-related modulation of the projection beams. Therefore the characteristic of holograms is utilized of storing several images with slightly changed recording condition above one another but independently of one another in the same hologram.

Also in the case of video screen holograms which are recorded by means of pulsed lasers, the size of the interfering image speckles which occur during the image reproduction by means of lasers can therefore be changed.

The method described here of recording a scattering holographic video screen can also be used for recording the function of a plane mirror which basically represents only a borderline case of a scattering surface. Because of their selectivity in the wavelength, such holographic mirrors can advantageously be used as auxiliary elements in the recording devices or in the projectors.

CLAIMS:

1. Method of producing video screen holograms in which a real video screen (11; 31; 41; 51) is illuminated by narrowband light in order to generate a hologram of the real video screen, characterized in that a plurality of individual recordings is made, in each case only a partial area (11a) of the real video screen (11; 31; 41; 51) being illuminated so that the video screen hologram of the entire video screen is obtained by the composition and/or superimposition of the individual recordings.

2. Method according to Claim 1, characterized in that the illumination takes place by means of a scanning pulsed laser beam (13; 33; 43; 53).

3. Method according to Claim 2, characterized in that the pulse duration is dimensioned such that the movement of the laser beam (13; 33; 43; 53) over the video screen (11; 31; 41; 51) has no influence on the interference of the light waves in the hologram.

4. Method according to one or several of the preceding claims,

characterized in that the recorded partial areas (11a) of the video screen (11; 31; 41; 51) correspond at least to the size of image pixels.

5. Method according to one or several of the preceding claims,
characterized in that the lumination takes place by means of a pulsed diode-pumped solid-state continuous-wave laser (16).

6. Method according to one or several of the preceding claims,
characterized in that a frequency conversion takes place in one or several of the wavelength ranges red, green, blue.

7. Method according to one or several of the preceding claims,
characterized in that a contact hologram or a video screen hologram is produced.

8. Method according to one or several of the preceding claims,
characterized in that a transmission hologram or a reflection hologram is produced.

9. Method according to one or several of the preceding

claims,
characterized in that laser beams (13; 33; 43; 53) of a coherence length are generated which is greater than the difference of the light paths between the object beam and the reference beam.

10. Method according to one or several of Claims 2 to 9, characterized in that the scanning rate and the pulse duration are mutually coordinated such that the movement of the laser beam (13; 33; 43; 53) during a pulse is smaller than 1/10 of the wavelength.

11. Method according to one or several of the preceding claims,
characterized in that a repeated scanning of the video screen surface takes place by means of a respectively phase-shifted laser beam (13; 33; 43; 53).

12. Method according to one or several of the preceding claims,
characterized in that the distribution of the lumination in the hologram is measured in order to correct the lumination in the case of a subsequent lumination cycle.

13. Method according to one or several of the preceding

claims,
characterized in that several luminations are carried out with mutually perpendicularly polarized light or laser beams (13; 33; 43; 53) in order to produce two mutually independent screen images in the hologram (12; 32; 42; 52).

14. Method according to one or several of the preceding claims,
characterized in that several luminations are carried out with changed recording parameters, such as a changed site of the real video screen or a changed place of origin of the reference beam.

15. Method according to one or several of the preceding claims,
characterized in that the lumination takes place simultaneously by light or laser beams (13; 33; 43; 53) of the primary colors red, green, blue which are coaxially adjusted on a beam axis.

16. Device for producing video screen holograms, having a narrowband light source (16; 39; 49; 59; 60) for illuminating a real video screen (11; 31; 41; 51), which is arranged such that the light (17; 30; 40; 50) emanating from the video screen is superimposed with respect to a reference

beam in order to produce a hologram of the video screen, characterized by a scanning device (14, 15; 34, 35; 47, 48; 47', 48'; 57, 58) for guiding the light radiation emanating from the light source over the video screen, the light source generating pulsed light radiation.

17. Device according to Claim 16, characterized in that the light source (60) simultaneously generates red, green and blue laser radiation.

18. Device according to Claim 16 or 17, characterized in that the light source (60) comprises a laser system according to one of Claims 19 to 20.

19. Laser system for producing video screen holograms by means of RGB beams, having a laser beam source (61, 62) for generating laser radiation (13; 33; 43; 53), a frequency conversion device (63), and an optical parametric oscillator (65), characterized in that the laser beam source comprises a pulsed q-switched single-frequency IR laser oscillator (61).

20. Laser system according to Claim 19, characterized in that the laser beam source comprises a laser amplifier (62) which is connected behind the q-switched

single-frequency IR laser oscillator (61).

21. Video screen hologram having a holographic recording material (12; 32; 42; 52) in which a real video screen (11; 31; 41; 51) is stored as a hologram, characterized in that the video screen hologram contains a plurality of individual recordings, in which in each case a partial area (11a) of the real video screen (11; 31; 41; 51) is imaged as a hologram, the whole image of the video screen resulting from assembled and/or superimposed individual recordings (11a).

22. Video screen hologram according to Claim 21, characterized in that it is produced according to the method of one or several of Claims 1 to 15.

ABSTRACT:

In the case of a method of producing video screen holograms, a real video screen (11) is illuminated by means of a narrowband light (13) for producing a hologram (12) of the real video screen. In this case, a plurality of individual recordings is carried out, only a partial area respectively of the real video screen being imaged in the hologram (12). The individual recordings take place, for example, by means of a scanning pulsed laser beam. The individual recordings are assembled to form the video screen hologram of the entire video screen (11). A recording device comprises a scanning device for guiding the light radiation (13) over the video screen (11) and a light source (16) which generates pulsed light radiation. The light source (16) is, for example, a laser system with a pulsed q-switched oscillator and with an optical parametric oscillator.

[Figure 1]

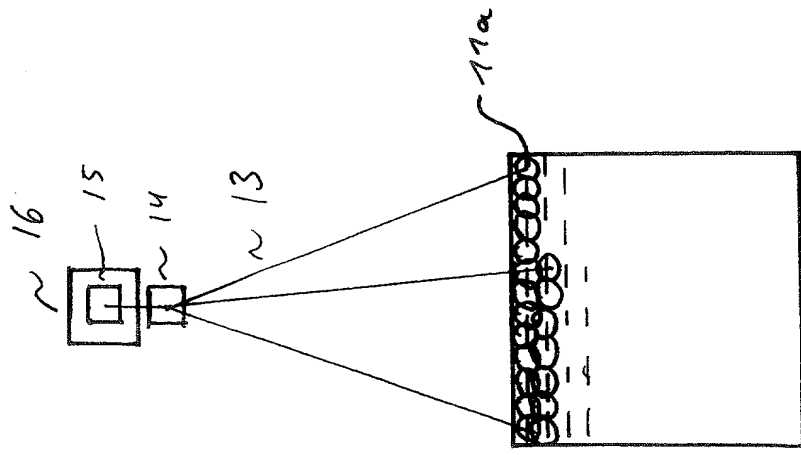


Fig. 2

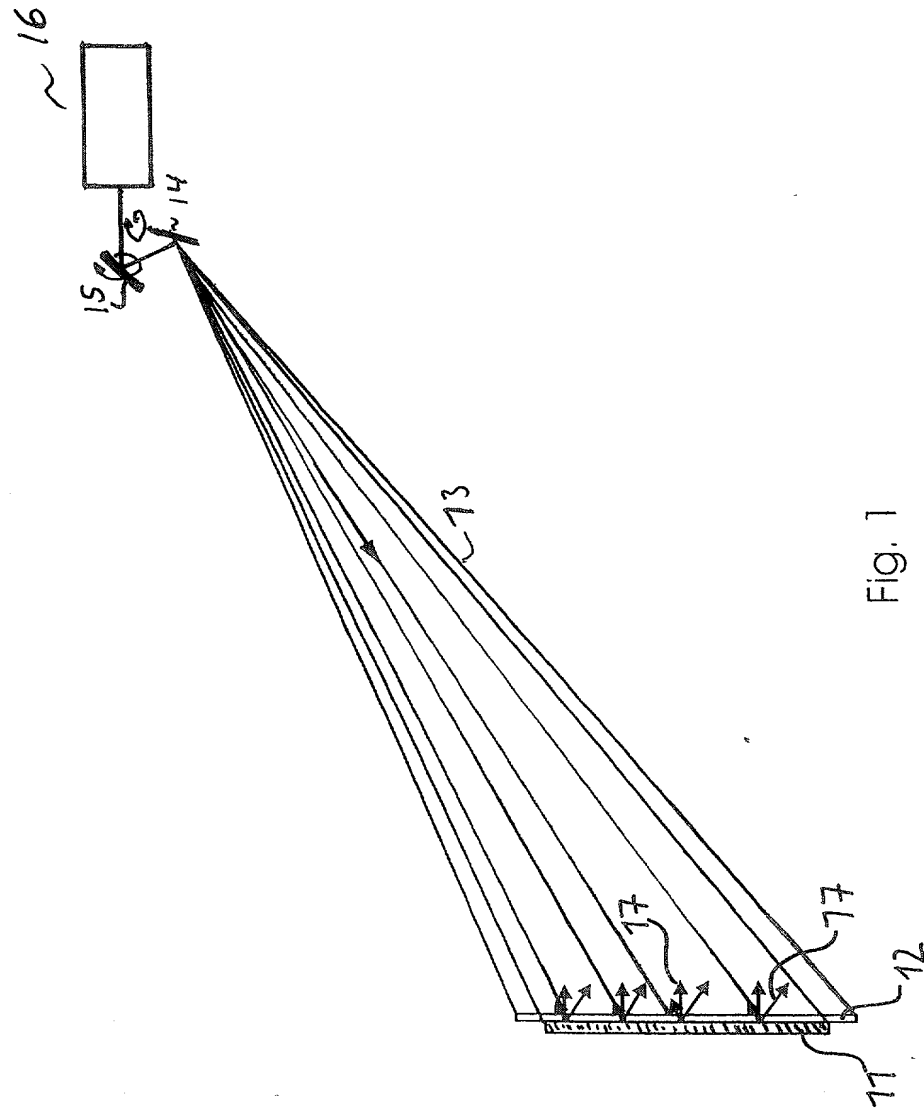


Fig. 1

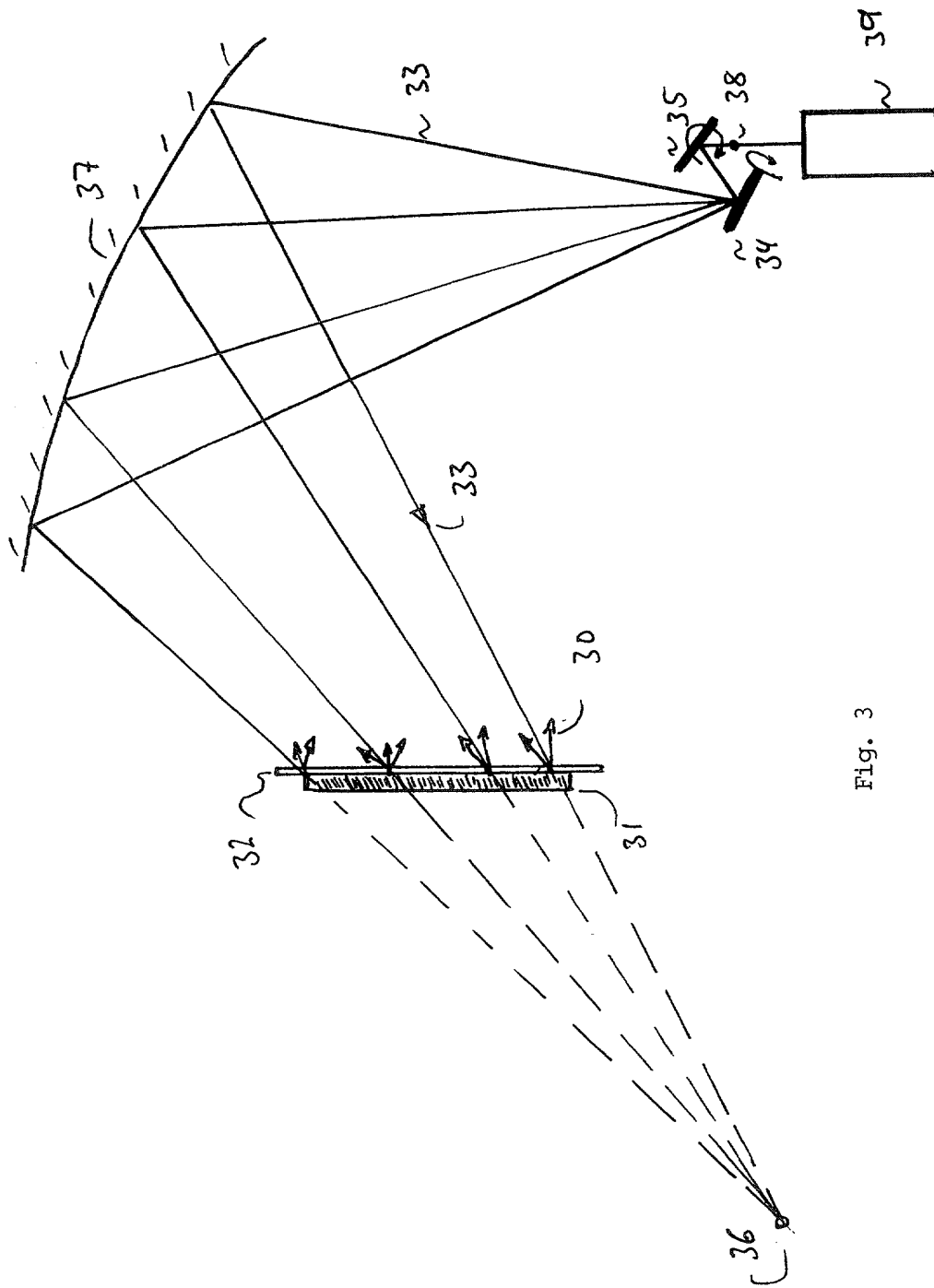
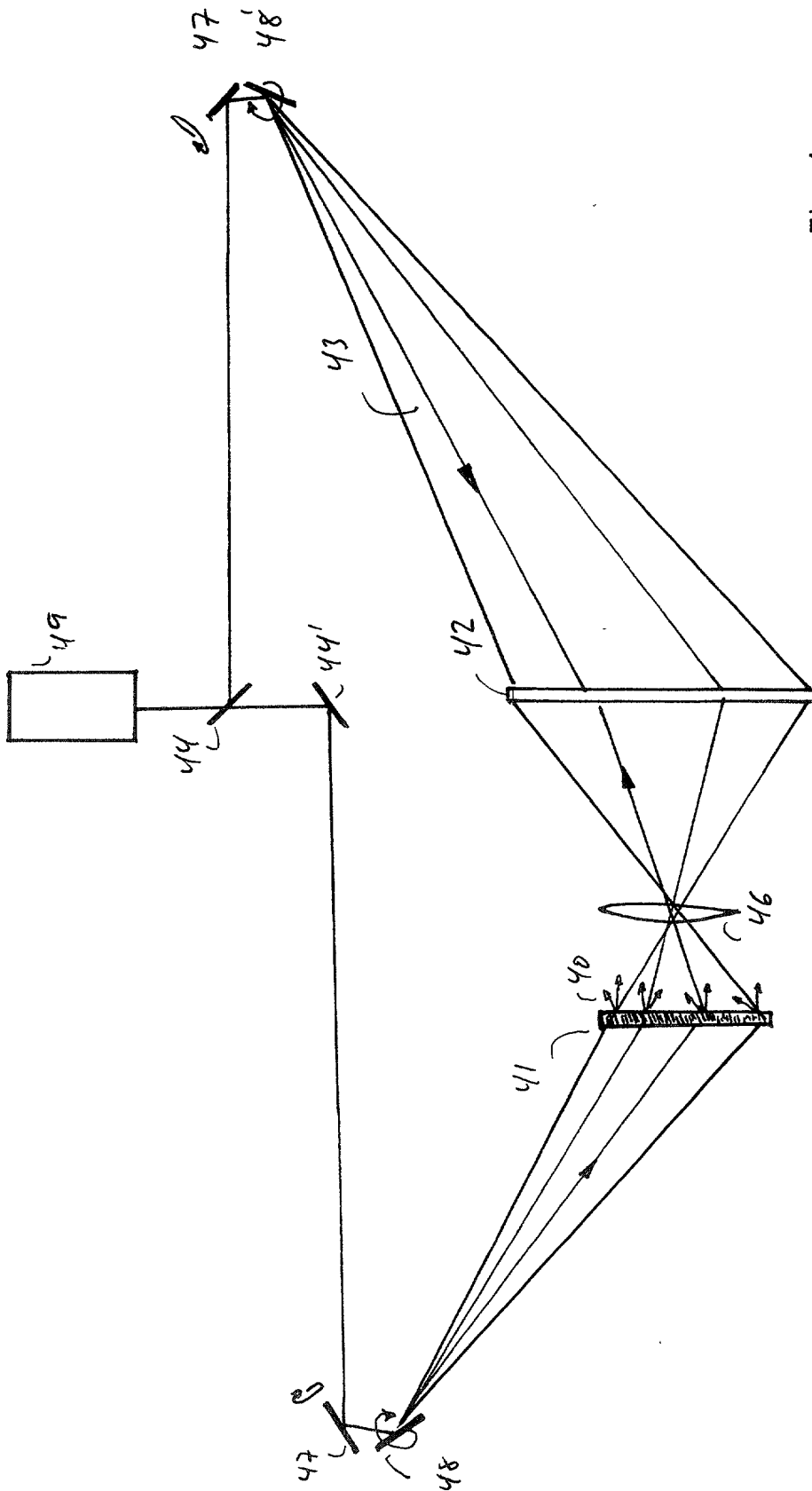


Fig. 3



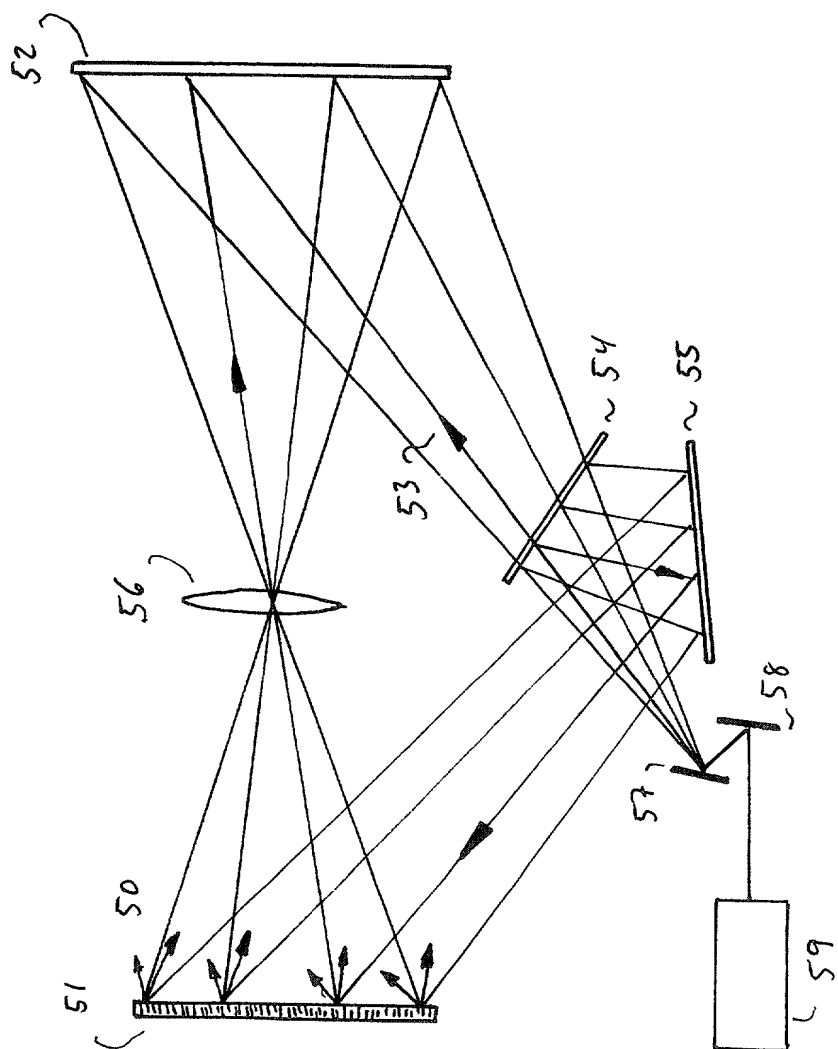


Fig. 5

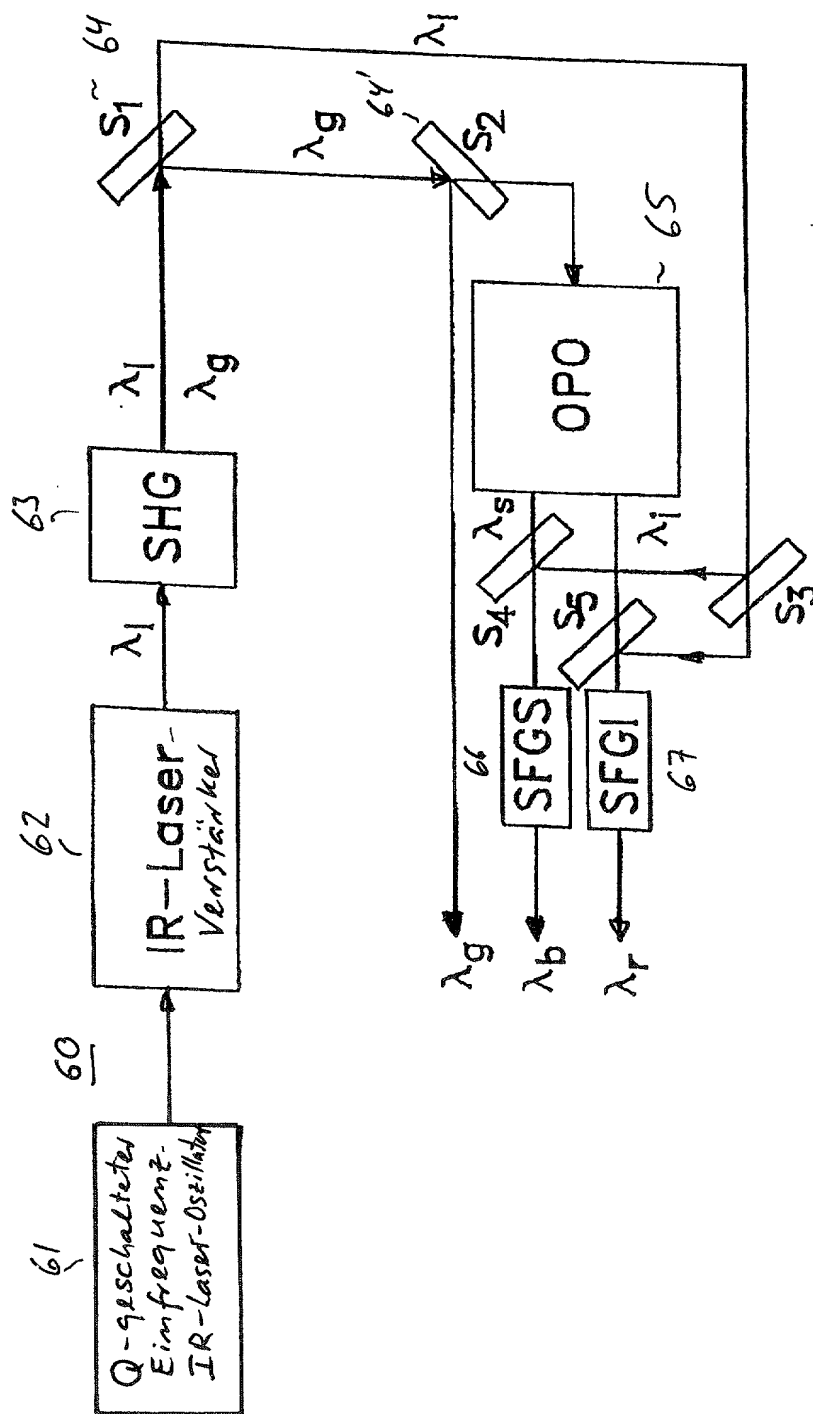


Fig. 6

Clean Version of Substitute Specification
Attorney Docket No. 420/50815

**METHOD, DEVICE AND LASER SYSTEM FOR PRODUCING VIDEO SCREEN
HOLOGRAMS AS WELL AS A VIDEO SCREEN HOLOGRAM**

BACKGROUND AND SUMMARY OF THE INVENTION

[0001] This application claims the priority of German patent document 199 34 162. 1, filed 21 July 1999 and PCT International Application No. PCT/DE00/02220, filed 6 July 2000, the disclosure of which is expressly incorporated by reference herein.

[0002] The invention relates to a method and apparatus system for producing video screen holograms, and to a video screen hologram.

[0003] Video screen holograms, which are produced as holographic images of real white video screens or video projection screens and are recorded by means of lasers in the primary colors red, green and blue (rgb), have the advantage that they are effective only within a narrow spectral range about the recording wavelength, and at the same time only within a very limited projection angle about the direction of incidence of the reference beam during the preceding hologram recording. The method of operation of such screens or holographic video screens

is described in detail in German Patent Applications No. 19700162.9 and No. 19703592.2.

[0004] As the light sources for the projection, rgb lasers in the continuous wave mode and in the pulsed mode as well as rgb light-emitting diodes can mainly be used. The image build-up can optionally be implemented by the serial scanning of a collimated laser beam or by the imaging of an image modulator in the expanded beam of a laser or a light-emitting diode onto the screen. Holographic video screens can be produced for both front and rear projection. Because of their wavelength selectivity and directional selectivity, bright, high-contrast images of a high color fidelity can be projected onto video screen holograms even in a daylight environment. The projector with the narrowband light sources is placed at the beam origin of the divergent reference beam. Only from there will the projection light be efficiently diffracted out of the hologram toward the viewer. The diffuse broadband ambient light, for example, can traverse the video screen hologram unhindered from all other directions of incidence.

[0005] U.S. Patent No. 4,500,163 discloses, for example, a holographic projection screen which has an arrangement of partial screen surfaces. Each partial screen surface is formed by a hologram, during whose recording a diffuser is holographically

imaged as an object by means of an objective beam and a reference beam in a photo plate. This is to permit a speckle-free imaging for large-surface, semicircular projection screens.

[0006] U.S. Patent 5,926,294 also shows the production of a hologram element in which a diffuser plate is holographically imaged as an objective. The hologram elements are assembled to form a projection screen.

[0007] For the reproduction or the projection of images onto video screen holograms, for example, rgb lasers are used, as described in "RBG Optical Parametric Oscillator Source", K. Snell et al., Aerosense 99, and in German Patent Documents DE 195 04 047 and DE 44 32 029.

[0008] The possible applications of video screen holograms extend over the broad field of small displays (for example, for a single person in vehicles and airplanes or at office workstations), to large-surface screens for several viewers at events. Smaller displays can be recorded by means of frequency-stable rgb continuous-wave lasers. In this case, the high requirements with respect to the stability of the laser and of the course of the beam and the connected high expenditures are disadvantageous and result in high cost.

[0009] An image representation on large video screen holograms which is independent of the ambient light would be very attractive, for example, for many different applications in the home and the office, for television, computers and electronic cinema and for projections in lecture halls, movie theaters and open-air theaters. However, the production of larger video screens, for example, of the size of typewriter paper (DIN A4) or larger, presents considerable technical difficulties.

[0010] First, the output power of the strongest continuous-wave lasers for hologram recordings is currently limited to only a few watts, which, for the particularly suitable silver halide and photo polymer materials, starting at a size of 1 m², requires a lumination time of tens of minutes. For these long lumination times, the requirements for the mechanical and thermal stability of the material, with respect to the optical components of the beam path and with respect to the frequency stability of the laser, are particularly high.

[0011] Second, during recording of the hologram, the object beam and reference beam must be expanded at the expense of the light output over the size of the video screen and of the hologram, because the radial intensity distribution is not constant over the laser beam. Rather, it follows a normal distribution which requires a considerable widening in order to

achieve a lighting which is as homogeneous as possible over the surface of the holograms. When several video screen holograms are joined together to create a large video screen hologram, the intensity drop toward the edges of the individual luminated holograms is particularly disturbing because a periodic shadow pattern then runs through the entire video screen during the projection.

[0012] Third, the luminating of the three rgb colors of three lasers into the same hologram results in difficulties because a uniform luminating of all three lasers over a larger surface is difficult to achieve. Because the wavelengths of the lasers are clearly different, differences occur in the beam transmission by refraction, diffraction and scattering at different points of the entire beam path, which leads to a nonuniform color display and is difficult to eliminate in the case of an imaging over an extensive surface.

[0013] It is therefore an object of the present invention to provide a method and apparatus which can produce high-quality small and large-surface video screen holograms in a simple manner.

[0014] Another object of the invention is to create a video screen hologram which can also be implemented on a large-surface

without degradation of the image quality during projection.

[0015] These and other objects and advantages are achieved by the method and apparatus for producing video screen holograms according to the invention, in which a real video screen is illuminated by means of a narrowband light to produce a hologram of the real video screen, and a large number of individual recordings are made in which only one partial area of the real video screen is illuminated. In this manner, a video screen hologram of the entire video screen is obtained by a composition and/or superimposing of the individual recordings. Because the illumination is performed by means of a scanning pulsed laser beam, it is possible to use only very brief luminating times so that disturbances during the lumination (for example, by shocks or other instabilities) are avoided. Furthermore, there is no occurrence of intensity reductions at the edge or of periodic shadow patterns, and a uniform color display becomes possible on large surfaces.

[0016] The pulse duration is, for example, dimensioned such that the movement of the laser beam over the video screen has no influence on the interference of the light waves in the hologram. The recorded partial areas of the video screen preferably correspond to the size of image pixels or are larger. In

particular, the lumination can take place by means of a pulsed diode-pumped solid-state continuous-wave laser.

[0017] A frequency conversion preferably takes place in one or more of the wavelength ranges red, green, blue. For example, a contact hologram or a video screen plane hologram is produced. A transmission hologram or a reflection hologram may also be produced. Laser beams are preferably generated with a coherence length which is greater than the difference of the light paths between the object beam and the reference beam. The scanning rate and the pulse duration are, for example, coordinated with one another such that the movement of the laser beam during a pulse is less than 1/10 of the wavelength.

[0018] Preferably, the video screen surface is scanned repeatedly by means of a respectively phase-shifted laser beam.

The distribution of the lumination can be measured in order to correct the lumination during a subsequent lumination cycle. Several luminations may also be carried out by means of light rays or laser beams which are polarized perpendicular to one another in order to produce two mutually independent screen images in the hologram. Furthermore, several luminations with changed recording parameters can be carried out, for example, a changed site of the real video screen or a changed place of origin of the reference beam. The lumination preferably takes

place simultaneously by means of light rays or laser beams of the primary colors red, green, blue, which are coaxially adjusted on a beam axis.

[0019] The device according to the invention for producing video screen holograms has a narrow-band light source for illuminating a real video screen. This light source is, for example, arranged such that the light emanating from the video screen is superimposed with a reference beam in order to produce a hologram of the video screen, in which case, a scanning device is provided for guiding the light radiation emanating from the light source over the video screen, the light source generating a pulsed light radiation. As a result, high-quality large-surface video screen holograms can also be produced in a simple manner.

[0020] The light source preferably simultaneously generates a red, green and blue laser radiation. The light source comprises particularly a laser system which will be described in the following.

[0021] The laser system used for producing RGB rays is suitable particularly for the generating of video screen holograms. It comprises a laser beam source for generating laser radiation, a frequency conversion device, and an optical-

parametric oscillator, the laser beam source comprising a pulsed q-switched laser oscillator. By means of this laser system, large-surface video screen holograms for a color projection with a high image quality can be produced in a simple manner.

[0022] The q-switched laser oscillator is preferably a single-frequency IR oscillator. The laser beam source has, for example, a laser amplifier which is connected behind the q-switched laser oscillator. The video screen hologram according to the invention has a holographic recording material in which a real video screen is stored as a hologram, and contains a large number of individual recordings in each of which a partial area of the real video screen is imaged as a hologram, the entire image of the video screen resulting from assembled and/or superimposed individual recordings. This results in a high-quality image reproduction, even in the case of a large-surface implementation of the video screen hologram.

[0023] The video screen hologram is preferably produced according to the method of the invention.

[0024] Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Figure 1 is a schematic lateral view of an arrangement for recording a reflection video screen image hologram as a contact hologram;

[0026] Figure 2 is a top view of the arrangement according to Figure 1;

[0027] Figure 3 is a schematic view of an arrangement for recording a transmission video screen hologram as a contact hologram;

[0028] Figure 4 is a view of an arrangement for recording a video screen reflection hologram for a front projection;

[0029] Figure 5 is a view of an arrangement for recording a transmission video screen hologram for a rear projection as an image plane hologram; and

[0030] Figure 6 is a schematic view of a laser system according to the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0031] Figure 1 is a schematic lateral view which illustrates the recording of a reflection hologram of a video screen as a contact hologram for later front projection. A holographic recording material 12 is in contact with a video screen 11. A laser beam bundle 13 from a rapidly pulsed laser 16 is scanned by means of scanners 14 and 15 over the recording material 12 in two axis directions x and y in a surface-covering manner, for example, by means of a circular-shaped laser beam spot. Figure 2 is a top view of the holographic recording material 12. The laser beam 13 successively illuminates a partial area 11a of the recording material 12 and of the video screen 11 situated behind the latter. Differently shaped laser spots, such as a rectangle, may also be used. A portion of the impinging laser radiation 13 is allowed by the hologram or the recording material 12 to pass through and impinges on the real video screen 11 which scatters radiation 17 as object light waves back into the hologram 12. There, the object light waves again impinge on the incident beam 13 and, together with its waves, form holographic interference patterns which are stored by the luminating process as a hologram in the recording material 12. Many different scanning techniques can be used, such as raster scans, sinusoidal scans or spiral scans.

[0032] Thus, the video screen hologram is not recorded as a whole in one piece as an image of the real video screen 11 but in a very large number of individual recordings, in each of which only small portions 11a of the real video screen 11 are illuminated. The entire image of the video screen 11 will then be obtained as a composition or superimposition of the large number of individual recordings, for example, in the manner of image pixels.

[0033] The produced video screen hologram is constructed as a contact hologram or as a so-called image plane hologram, in which the projected image when displayed appears in the hologram plane. By luminating screens in the primary colors red, green and blue into the same hologram layer 12 or into three layers laminated onto one another, colored images can later also be projected onto the holographic screen.

[0034] Contact holograms have the advantage of a simple optical construction during the recording. As illustrated in Figure 1, the hologram is therefore placed in contact onto the real video screen 11, for example, a reflecting scattering lens or transmitting obscured glass and is luminated together with the reference beam without any additional object illuminating. During the projection, the angle of the backscattered projection

light from the hologram 12 in the direction of the viewer is the same as that of the real video screen with respect to the recording light beam 13.

[0035] The invention is based on the fact that the holographic video screen or the hologram 12 must reflect the optical characteristics of the image pixels, that is, the brightness (half-tone), the color, the polarization and the angle of radiation only individually for each pixel from the screen. An optical linking between adjacent pixels does not exist, and a video screen as a contact or image plane hologram has only a two-dimensional structure. So that the hologram 12 can reflect this method of operation of a flat video screen in the hologram plane, it is not absolutely necessary to record the real video screen 11 in a single lumination over an extended hologram surface, as takes place in the case of holograms of three-dimensional objects, but the video screen may be constructed as an assembled film or a film constructed in a mosaic-type of separate individual recordings of partial areas 11a of a video screen. These partial areas 11a may therefore be reduced to the size of an individual image pixel.

[0036] The holographic video screen is recorded by luminating the real larger video screen 11 with a rapidly pulsed laser beam 13 which is scanned without gaps over the entire surface. To

ensure that the movement of the beam 13 over the screen 11 or over the recording material 12 has no influence on the interference of the light waves in the hologram 12, on the one hand, the pulse duration of the laser 16 is kept sufficiently short, and on the other hand, the coherence length of the laser light is sufficient to form the interferences. In order to achieve a particularly economical production of the holographic screen, the pulse repetition frequency of the laser 16 and its median power is sufficiently high so that a short luminating time is achieved.

[0037] Suitable lasers for this type of holographic lumination are, for example, high-power, rapidly pulsed, diode-pumped infrared solid-state continuous-wave lasers with only a single longitudinal mode whose radiation is displaced by frequency conversion into the red, green and blue wavelength range. The scanning of the video screen surface can take place by means of commercially available laser beam scanners.

[0038] The partial holograms 11a are selected at least large enough that no disturbances occur, such as a reduction of contrast, color distortion and reduction of the image resolution in the later image reproduction by light diffraction or a fine structure of the holograms itself. Such disturbances are not expected if the partial holograms 11a are larger than the image

pixels of the projection. On the other hand, the size and the shape of the partial hologram 11a and the scanning rate can be selected such that, by means of the defined operating parameters of the recording laser, such as the median power and the pulse repetition frequency, an optimal irradiation and a homogeneous illumination of the hologram 12 is achieved without reducing the efficiency of the recording simultaneously by the movement of the scanning beam 13.

[0039] In general, for the recording of object holograms, the object itself must be illuminated by means of an object beam and the hologram must be illuminated by means of a reference beam. The light scattered by the object is then superimposed with the reference beam in the hologram film. In the case of the pulsed recording illustrated in which only a portion 11a of the real video screen 1 is illuminated as the object and simultaneously a portion of the hologram 12 is illuminated directly by means of the pulsed reference beam 13, the luminations are implemented in a synchronously superimposed manner. This can easily be implemented by means of contact holograms, in which the hologram film 12 is placed directly on the real video screen 11 and the reference beam 13 is used both for illuminating the hologram 12 and for illuminating the video screen 11.

[0040] In the case of image plane holograms, the video screen

is imaged by means of a lens into the hologram. So that the partial illumination of the video screen with the object beam and the hologram with the reference beam mutually overlap, the two scanning beams must be mutually synchronized during their movement, such that the imaged spot of the video screen in the hologram and the spot of the reference beam will in each case be congruent.

[0041] During the lumination, the light waves in the object beam and the reference beam must be coherently imposed on one another in the hologram. This means that the coherence length of the used illumination laser 16 has to be at least as large as or larger than the difference of the light paths between the waves of the object beam and the reference beam which originate from a common beam, until they meet again in the hologram 12.

Within the scope of the invention, this requirement can be met by a corresponding design of the beam guidance and the build-ups of the holograms with respect to the coherence length of the available lasers.

[0042] The movement of the interfering waves in the hologram by the scanning beams (object beam and reference beam) during the pulse duration, with respect to one another and with respect to the hologram film, amounts to no more than fractions of the wavelength ($< \lambda/10$). This condition is met by a corresponding

adjustment of the scanning rate corresponding to the pulse duration of the laser. In the case of a pulse duration of 10 ns and a scanning rate of 5 m/sec, the movement of the beam is, for example, 50 nm, which corresponds to approximately $\lambda/10$.

[0043] During the scanning with a pulsed radiation at a constant power from pulse to pulse, a large hologram surface can be covered with a uniform average intensity distribution. However, the lumination (that is, the light intensity times the time), depending on the ratio of the scanning rate to the pulse repetition frequency of the beam with the Gaussian intensity profile, will be periodically modulated over the whole surface along the scanning sweep. The invention therefore also provides that this periodic local non-uniformity of the illumination as well as inhomogeneities in the hologram thickness, for example, in the case of a mosaic-type laying of several holograms side-by-side, are compensated by a repeated scanning of the same surface by means of a phase-shifted scanning beam or by controlling the pulsed power. Here, the invention partly utilizes the characteristic of hologram recordings that several object luminations can be stored in an overlapping manner and independently of one another in a single hologram.

[0044] So that this lumination process can take place automatically, in one embodiment of the invention (not shown),

the distribution of the lumination is monitored by a calibrated backscatter sensor which is arranged in the beam path of the illumination laser coaxially to the pulsed lumination beam. As an alternative, monitoring cameras may continuously measure the laser illumination over the entire hologram surface. The lumination pattern thus obtained can be stored by a microprocessor or computer, and can be used during subsequent repeated scanning cycles over the entire hologram surface by controlling the laser light intensity and surface distribution of the scanning figure for the subsequent correction of the lumination of the preceding lumination patterns.

[0045] After the development process, the optical characteristics of the video screen are stored in the hologram 12. Preferably, so-called thick holograms (10-20 μm) are used, for example, consisting of photopolymer, dichromate gelatin or silver halide materials. In comparison to thin holograms, thick holograms have the advantage that they particularly selectively diffract out light with the same wavelength as during the recording, specifically only when the angle of incidence of the reconstruction beam is the same as the angle of incidence of the reference beam during the recording.

[0046] The optimal accumulated lumination of the holograms differs for each material and for each wavelength. For

photopolymer materials, for example, it is at approximately 25 mJ/cm²; that is, for the lumination of 1 m² with a laser 1 W of median power, 250 seconds or approximately 4 minutes are required. In the case of silver halide films, a lumination of only approximately 0.5 mJ/cm², is necessary, so that the lumination time can be correspondingly shortened. Image plane holograms are recordings of screens imaged by means of lenses or mirrors, which screens are situated in the hologram plane. The angle of radiation of these holograms can be considerably narrowed by the imaging geometry, with a corresponding increase of the brightness of the image, which is very advantageous for many applications.

[0047] Figure 3 illustrates a recording of a contact hologram of a video screen 31 as a transmission hologram 32. In this case, it is necessary that a reference bundle of beams 33, whose beam path coincides with the projection beam during the later image reproduction, impinges as a convergent partial beam bundle of a pulsed laser 39 on the hologram 32. The interference structures which then form in the hologram 32 as the result of the superimposition of scattered light 30 from the screen on the reference bundle 33 of beams, will then correspond to an image reproduction in a rear projection from the intersection or projection point 36, that is, the lengthening of the beam bundle 33. During the projection, the viewer will then stand opposite

the later projection point 36 on the opposite side of the hologram 12. The generating of a convergent bundle of beams from a two-axis scanner 34 and 35 can most easily be implemented by way of a mirror 37 of a long focal length which images the source point of the scanner 38 in the intersecting point 36. The hologram 32 and the real video screen 31 are then placed in a sectional plane of the beam path of the partial beam bundle 33.

[0048] Figure 4 illustrates a recording of a transmission hologram as an image plane hologram for the rear projection. Here, a real video screen 41 is imaged by means of a lens 46 on a hologram 42. Simultaneously, a reference beam bundle 43 impinges from the other side on the hologram 42. The two scanners with the x-y scanner mirrors 47 and 48 or 47' and 48' are synchronized such that the two illumination spots of the reference beam bundle 43 and of the illuminated surface 40 of the real screen in the hologram 41 are synchronously superimposed. The illumination beams for the real screen 42 and for the reference bundle 43 of beams are separated and deflected by means of separator mirrors 44 and deflecting mirrors 44' from the common laser 49.

[0049] Figure 5 illustrates a recording of an image plane hologram as a reflection hologram for the later front projection. In this case, a real screen 51 is imaged in a hologram plane 52

by means of a lens 56, and the image is synchronously superimposed there with a reference bundle 53 of beams. By means of a separator mirror 54, a portion of the reference bundle 53 of beams can be used for illuminating the real screen 51.

Additional auxiliary mirrors are required for compensating the space reflection of the lens 56, which is illustrated here for the one space plane on the example of the auxiliary mirror 55.

For the simultaneous scanning of the screen 51 and the hologram 52, only one pair of scanner mirrors 57 and 58 is used here in front of the pulsed laser 59.

[0050] In order to facilitate the recording of three-color or multicolor screens, for example, of the rgb colors, the beams of three rgb lasers or of one laser with a three-color rgb emission are coaxially adjusted with respect to an identical beam axis. During a joint scanning and luminating of the screen and of the hologram with the reference beam, the three colors are simultaneously on the real video screen. The reference beam also represents a superimposition of three rgb partial beams.

[0051] This simultaneous recording of all three rgb colors in the same hologram naturally requires that the hologram material is photosensitive to all colors. However, this also applies to a number of photopolymers and silver halide films as well as to individual dichromate gelatins.

[0052] For recording the video screen holograms described here with a rapidly pulsed rgb illumination, modern diode-pumped, q-switched infrared solid-state lasers are used with an emission in only one longitudinal resonator mode. The lasers are adjusted to the rgb emission at the suitable rgb wavelengths by a classical frequency conversion, such as frequency doubling, optically parametric processes and summation and difference frequency formation, in various non-linear crystals.

[0053] Separate lasers can be used for the individual colors, but it is more advantageous to use lasers which have a single joint q-switched laser oscillator. The lasers have joint amplifier stages on the output side and a joint optical-parametric oscillator which splits the fundamental wave of the laser or its frequency-doubling wave into two partial waves of a longer wavelength (idler and signal wave). A subsequent beam separation is used for separating the primary radiation into different beam branches, where different further frequency conversions take place, such as frequency doubling, frequency summation and difference formation for producing the individual colors.

[0054] A significant advantage of such a joint primary laser is the fact that the emission of all three rgb color branches

takes place completely synchronously with the same pulse repetition frequency, in a solid phase and with a comparable spectral width, coherence length and beam divergence. This permits a joint recording of the video screen holograms simultaneously in all colors.

[0055] RGB lasers, which are based on this basic concept of a joint primary laser with a subsequent frequency conversion in passive non-linear crystals to the three rgb colors, are described, for example, in the above-mentioned German Patent Document DE 195 04 047, "Laser System for Color Image Projection", and in German Patent Document DE 44 32, 029, "Laser-Supported Color Image Display and Projection Device". The diode-pumped solid-state lasers described there are operated in the mode-locked continuous-wave mode. However, with respect to the recording of video screen holograms, they have the disadvantage that they emit a wide frequency spectrum of individual longitudinal modes, that is, of a short coherence length in the primary emission as well as after the frequency conversion.

[0056] Figure 6 illustrates a laser according to the invention which is particularly suitable for the above-described pulsed video screen hologram recordings. In this case, instead of a mode-locked laser, a rapidly pulsed q-switched single-frequency IR oscillator 61 of an Nd laser, such as Nd:YLF, Nd:YAG or

Nd:YVO, is provided; that is, the oscillator 61 has a single longitudinal mode. The power amplification of the pulses takes place in a solid-state laser amplifier 62 of the same materials. An optical parametric oscillator 65 is provided for subsequent frequency splitting. This oscillator can be adjusted in its wavelength by way of the temperature of the non-linear material and/or the adjustment of the axis angle in the beam path. As a result, the wavelength of the effective rgb radiation can also be adjusted during the subsequent frequency conversion. This is advantageous for precisely adapting the recording wavelength to the later reproduction wavelength. A frequency doubling and summation frequency formation also takes place. The oscillator 61, is a q-switched Nd:YAG in the longitudinal single-mode operation. The laser amplifier 62 is an Nd:YAG or Nd:YVO amplifier chain. Furthermore, a frequency doubler crystal 63 is provided as well as beam separators 64, 64' for separating the fundamental radiation of the primary laser $\lambda_1=1.06 \mu\text{m}$ from the frequency-doubled green radiation $\lambda_g=0.53 \mu\text{m}$. The optical parametric oscillator 65 is pumped by means of the green beam λ_g and adjusted such that it generates two signal and idler beams (λ_s and λ_1 respectively), which have a suitable wavelength for a subsequent summation frequency formation in summation frequency generators 66, 67. In this case, the wavelengths λ_s and λ_1 are selected such that the summation frequency formation with the beams of the fundamental wavelength of the laser $\lambda_1 = 1.06 \mu\text{m}$ (or

1.04 μm), which remains after the frequency doubling, results in suitable wavelengths of red and blue. In contrast, the color green is taken over as part of the frequency-doubled radiation of the primary laser by way of splitting by the simple beam separator 64, 64'.

[0057] The suggested rapidly pulsed q-switched laser 61 is a continuous-wave laser oscillator with only one longitudinal fundamental mode which is operated in a pulsed operation of the resonator. A laser of this type is, for example, a diode-pumped solid-matter microchip laser, such as the Nd:YAG at a laser wavelength 1.06 μm with such a short resonator that it starts lasing only on a longitudinal mode. By means of an internal passive quality switch, for example, made from the known Cr^{4+} :YAG material, the resonator can be adjusted by doping with Cr^{4+} ions, for example, to 20 kHz pulse frequency with a pulse duration of 10 ns.

[0058] The IR-emission of the laser 61 is now highly amplified in the amplifier 62 which follows; for example, by means of the crystal Nd:YAG or Nd:YVO, by a factor 10-100, without creating interfering higher longitudinal modes, also while maintaining the good beaming quality of the oscillator. After the amplification, the pulsed beam is then still frequency-doubled to the desired green wavelength 532 nm, which occurs here in a KTP crystal 63.

After the frequency doubling, which takes place here with an efficiency of approximately 30%, a portion of the primary radiation with a wavelength of 1.06 μm remains for a further use in the subsequent stages.

[0059] A second possibility is the use of passively quality-switched Nd:YAG ring lasers with the same Cr^{4+} YAG quality switch, a similar pulse repetition frequency, but a better frequency stability and a higher median power. By means of subsequent amplifier stages as in the previous case, a median power of 10-39 W can be generated in a longitudinal mode.

[0060] One possibility is the use of a laser actively quality switched by means of an acoustic-optical switch with an internal standard for adjusting a single-mode operation. This arrangement, however, requires slightly higher expenditures in comparison to the second process.

[0061] Q-switched continuous-wave lasers of the type described here have a pulse repetition frequency of 10-20 kHz, a pulse width of 5-20 ns and a frequency bandwidth of the laser emission below 100 MHz. They can be designed with an amplifier stage such that, after the frequency doubling 1 W green emission is created, and by means of two or three stages, up to 10 W green radiation is generated and 30 W infrared radiation is generated in the

device. After the conversion in the optical parametric oscillator 65 and a further frequency doubling or summation frequency formation, all rgb beams can then be produced with a median power of several watts. A significant advantage of this concept is also that the colors blue and red can be continuously displaced by the adjustment of the wavelengths of the idler and signal wavelength λ_s , λ_i in the optical parametric oscillator 65 for the adaptation to the wavelength of the later image projection lasers.

[0062] By means of the characteristic laser data, such laser systems are particularly suitable for the recording of the video screen holograms. If, for example, the pulse duration of the laser amounts to 10 ns and the scanning rate amounts to 5 m/sec, the beam moves laterally by 5×10^{-8} m during this pulse duration, which corresponds to 1/10 of the wavelength at, for example, 500 nm. This small displacement has no noticeable influence on the quality of the interference pattern in the hologram. If the pulse frequency were, for example, 20 kHz, the beam would move from pulse to pulse at this scanning rate by 1/4 mm. The coherence length of a $\Delta t = 10$ ns single-mode pulse amounts to approximately $\Delta t \cdot c = 3$ m, wherein c is the speed of light. The difference of the travelling paths of the object and reference beam must not exceed this value, which can easily be observed in the case of all suggested embodiments of the

holograms.

[0063] Therefore, video screen holograms can be designed either for a front projection as a reflection hologram, or for a rear projection as a transmission hologram. Recording in both the contact process with the real video screen and as an image plane hologram (that is, after an imaging of the video screen on the hologram, as illustrated above) are suitable for both processes. In all cases, the object beam and the reference beam are moved synchronously over the hologram.

[0064] Only light sources with an identical linear polarization can interfere with one another and be stored as a holographic image of screens in a hologram; that is, only light waves of an identical linear polarization in the reference beam and the object beam can contribute to generating the image of the video screen. Therefore, the lasers used for the recording of the holograms are preferably polarized in a strictly linear manner in order to ensure the efficiency and the homogeneity of the illumination over the entire hologram surface. Since most lasers with a good beaming quality are strictly linearly polarized from the start, this does not cause any limitation of the recording technique.

[0065] For recording of video screens for stereoscopic image

reproduction, video screen materials are used which depolarize an impinging linearly polarized light beam by backscattering or by forward scattering. This applies to many projection screen materials for the rear projection with a good fine roughness of the surface or a slight volume scattering, and to almost all projection screens with a high volume scattering for rear projections. Since the reference beam also has a strict polarization direction of the laser, when a real video screen is recorded, this polarization direction is maintained in the hologram. If now two recordings are successively made of the same screen, in which the polarization direction of the reference beam is rotated from one to the other by 90°, two independent screen images are created in the same video screen hologram, each being effective only with respect to a projection beam with a defined polarization direction. Both screen images affect mutually orthogonal polarized projection beams. Thus, also prerequisites are met for the projection of mutually orthogonally polarized stereo images and their stereoscopic viewing by means of polarization glasses.

[0066] The switch-over of the polarization by 90° in the reference beam can be carried out very simply by rotating a $\lambda/2$ -plate in the beam path behind the outlet aperture of a strictly linearly polarized illumination laser.

[0067] If several video screen recordings are made of the same screen successively into the same hologram while the site of the whole screen or of the place of origin of the reference beam are changed, the interfering speckle images are superimposed coherently with a statistical size distribution. Together, they represent a new virtual screen after the luminations, which screen has a significantly higher fine structure than the real original screen. This results in a displacement of the entire appearance image toward larger speckles which then, during the subsequent image reproduction, can be eliminated more easily by a slight local or time-related modulation of the projection beams. Therefore this technique utilizes the ability of holograms to store several images with slightly changed recording condition above one another but independently of one another in the same hologram. Also in the case of video screen holograms which are recorded by means of pulsed lasers, the size of the interfering image speckles which occur during the image reproduction by means of lasers can therefore be changed.

[0068] The method described here of recording a scattering holographic video screen can also be used for recording the function of a plane mirror which basically represents only a borderline case of a scattering surface. Because of their selectivity in the wavelength, such holographic mirrors can

advantageously be used as auxiliary elements in the recording devices or in the projectors.

[0069] The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.

Marked-up Substitute Specification
Attorney Docket No. 420/50815

**METHOD, DEVICE AND LASER SYSTEM FOR PRODUCING VIDEO SCREEN
HOLOGRAMS AS WELL AS A VIDEO SCREEN HOLOGRAM**

BACKGROUND AND SUMMARY OF THE INVENTION

This application claims the priority of German patent document 199 34 162. 1, filed 21 July 1999 and PCT International Application No. PCT/DE00/02220, filed 6 July 2000, the disclosure of which is expressly incorporated by reference herein.

The invention relates to a method and apparatus system for producing video screen holograms, and to a video screen hologram.

Video screen holograms, which are produced as holographic images of real white video screens or video projection screens and are recorded by means of lasers in the primary colors red, green and blue (rgb), have the advantage that they are effective only within a narrow spectral range about the recording wavelength, and at the same time only within a very limited projection angle about the direction of incidence of the reference beam during the preceding hologram recording. The method of operation of such screens or holographic video screens is described in detail in German Patent Applications No. 19700162.9 and No. 19703592.2.

As the light sources for the projection, rgb lasers in the continuous wave mode and in the pulsed mode as well as rgb light-emitting diodes can mainly be used. The image build-up can optionally be implemented by the serial scanning of a collimated laser beam or by the imaging of an image modulator in the expanded beam of a laser or a light-emitting diode onto the screen. Holographic video screens can be produced for both front and rear projection. Because of their wavelength selectivity and directional selectivity, bright, high-contrast images of a high color fidelity can be projected onto video screen holograms even in a daylight environment. The projector with the narrowband light sources is placed at the beam origin of the divergent reference beam. Only from there will the projection light be efficiently diffracted out of the hologram toward the viewer. The diffuse broadband ambient light, for example, can traverse the video screen hologram unhindered from all other directions of incidence.

U.S. Patent No. 4,500,163 discloses, for example, a holographic projection screen which has an arrangement of partial screen surfaces. Each partial screen surface is formed by a hologram, during whose recording a diffuser is holographically imaged as an object by means of an objective beam and a reference beam in a photo plate. This is to permit a speckle-free imaging

for large-surface, semicircular projection screens.

U.S. Patent 5,926,294 also shows the production of a
hologram element in which a diffuser plate is holographically
imaged as an objective. The hologram elements are assembled to
form a projection screen.

For the reproduction or the projection of images onto video
screen holograms, for example, rgb lasers are used, as described
in "RBG Optical Parametric Oscillator Source", K. Snell et al.,
Aerosense 99, and in German Patent Documents DE 195 04 047 and
DE 44 32 029.

The possible applications of video screen holograms extend
over the broad field of small displays (for example, for a single
person in vehicles and airplanes or at office workstations), to
large-surface screens for several viewers at events. Smaller
displays can be recorded by means of frequency-stable rgb
continuous-wave lasers. In this case, the high requirements with
respect to the stability of the laser and of the course of the
beam and the connected high expenditures are disadvantageous and
result in high cost.

An image representation on large video screen holograms
which is independent of the ambient light would be very

attractive, for example, for many different applications in the home and the office, for television, computers and electronic cinema and for projections in lecture halls, movie theaters and open-air theaters. However, the production of larger video screens, for example, of the size of typewriter paper (DIN A4) or larger, presents considerable technical difficulties.

First, the output power of the strongest continuous-wave lasers for hologram recordings is currently limited to only a few watts, which, for the particularly suitable silver halide and photo polymer materials, starting at a size of 1 m², requires a lumination time of tens of minutes. For these long lumination times, the requirements for the mechanical and thermal stability of the material, with respect to the optical components of the beam path and with respect to the frequency stability of the laser, are particularly high.

Second, during recording of the hologram, the object beam and reference beam must be expanded at the expense of the light output over the size of the video screen and of the hologram, because the radial intensity distribution is not constant over the laser beam. Rather, it follows a normal distribution which requires a considerable widening in order to achieve a lighting which is as homogeneous as possible over the surface of the holograms. When several video screen holograms are joined

together to create a large video screen hologram, the intensity drop toward the edges of the individual luminated holograms is particularly disturbing because a periodic shadow pattern then runs through the entire video screen during the projection.

Third, the luminating of the three rgb colors of three lasers into the same hologram results in difficulties because a uniform luminating of all three lasers over a larger surface is difficult to achieve. Because the wavelengths of the lasers are clearly different, differences occur in the beam transmission by refraction, diffraction and scattering at different points of the entire beam path, which leads to a nonuniform color display and is difficult to eliminate in the case of an imaging over an extensive surface.

It is therefore an object of the present invention to provide a method and apparatus which can produce high-quality small and large-surface video screen holograms in a simple manner.

Another object of the invention is to create a video screen hologram which can also be implemented on a large-surface without degradation of the image quality during projection.

These and other objects and advantages are achieved by the

method and apparatus for producing video screen holograms according to the invention, in which a real video screen is illuminated by means of a narrowband light to produce a hologram of the real video screen, and a large number of individual recordings are made in which only one partial area of the real video screen is illuminated. In this manner, a video screen hologram of the entire video screen is obtained by a composition and/or superimposing of the individual recordings. Because the illumination is performed by means of a scanning pulsed laser beam, it is possible to use only very brief luminating times so that disturbances during the lumination (for example, by shocks or other instabilities) are avoided. Furthermore, there is no occurrence of intensity reductions at the edge or of periodic shadow patterns, and a uniform color display becomes possible on large surfaces.

The pulse duration is, for example, dimensioned such that the movement of the laser beam over the video screen has no influence on the interference of the light waves in the hologram. The recorded partial areas of the video screen preferably correspond to the size of image pixels or are larger. In particular, the lumination can take place by means of a pulsed diode-pumped solid-state continuous-wave laser.

A frequency conversion preferably takes place in one or more

of the wavelength ranges red, green, blue. For example, a contact hologram or a video screen plane hologram is produced. A transmission hologram or a reflection hologram may also be produced. Laser beams are preferably generated with a coherence length which is greater than the difference of the light paths between the object beam and the reference beam. The scanning rate and the pulse duration are, for example, coordinated with one another such that the movement of the laser beam during a pulse is less than $1/10$ of the wavelength.

Preferably, the video screen surface is scanned repeatedly by means of a respectively phase-shifted laser beam. The distribution of the lumination can be measured in order to correct the lumination during a subsequent lumination cycle. Several luminations may also be carried out by means of light rays or laser beams which are polarized perpendicular to one another in order to produce two mutually independent screen images in the hologram. Furthermore, several luminations with changed recording parameters can be carried out, for example, a changed site of the real video screen or a changed place of origin of the reference beam. The lumination preferably takes place simultaneously by means of light rays or laser beams of the primary colors red, green, blue, which are coaxially adjusted on a beam axis.

The device according to the invention for producing video screen holograms has a narrow-band light source for illuminating a real video screen. This light source is, for example, arranged such that the light emanating from the video screen is superimposed with a reference beam in order to produce a hologram of the video screen, in which case, a scanning device is provided for guiding the light radiation emanating from the light source over the video screen, the light source generating a pulsed light radiation. As a result, high-quality large-surface video screen holograms can also be produced in a simple manner.

The light source preferably simultaneously generates a red, green and blue laser radiation. The light source comprises particularly a laser system which will be described in the following.

The laser system used for producing RGB rays is suitable particularly for the generating of video screen holograms. It comprises a laser beam source for generating laser radiation, a frequency conversion device, and an optical-parametric oscillator, the laser beam source comprising a pulsed q-switched laser oscillator. By means of this laser system, large-surface video screen holograms for a color projection with a high image quality can be produced in a simple manner.

The q-switched laser oscillator is preferably a single-frequency IR oscillator. The laser beam source has, for example, a laser amplifier which is connected behind the q-switched laser oscillator. The video screen hologram according to the invention has a holographic recording material in which a real video screen is stored as a hologram, and contains a large number of individual recordings in each of which a partial area of the real video screen is imaged as a hologram, the entire image of the video screen resulting from assembled and/or superimposed individual recordings. This results in a high-quality image reproduction, even in the case of a large-surface implementation of the video screen hologram.

The video screen hologram is preferably produced according to the method of the invention.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic lateral view of an arrangement for recording a reflection video screen image hologram as a contact hologram;

Figure 2 is a top view of the arrangement according to Figure 1;

Figure 3 is a schematic view of an arrangement for recording a transmission video screen hologram as a contact hologram;

Figure 4 is a view of an arrangement for recording a video screen reflection hologram for a front projection;

Figure 5 is a view of an arrangement for recording a transmission video screen hologram for a rear projection as an image plane hologram; and

Figure 6 is a schematic view of a laser system according to the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic lateral view which illustrates [of] the recording of a reflection hologram of a video screen as a contact hologram for [a] later front projection. A holographic

recording material 12 is in contact with a video screen 11. A laser beam bundle 13 from a rapidly pulsed laser 16 is scanned by means of scanners 14 and 15 over the recording material 12 in two axis directions x and y in a surface-covering manner, for example, by means of a circular-shaped laser beam spot. Figure 2 is a top view of the holographic recording material 12. The laser beam 13 successively illuminates a partial area 11a of the recording material 12 and of the video screen 11 situated behind the latter. Differently shaped laser spots, such as a rectangle, may also be used. A portion of the impinging laser radiation 13 is allowed by the hologram or the recording material 12 to pass through and impinges on the real video screen 11 which scatters radiation 17 as object light waves back into the hologram 12. There, the object light waves again impinge on the incident beam 13 and, together with its waves, form holographic interference patterns which are stored by the luminating process as a hologram in the recording material 12. Many different scanning [figures] techniques can be used, such as raster scans, sinusoidal scans or spiral scans.

Thus, the video screen hologram is not recorded as a whole in one piece as an image of the real video screen 11 but in a very large number of individual recordings, in each of which [in each case] only small portions 11a of the real video screen 11 are illuminated. The entire image of the video screen 11 will

then be obtained as a composition or superimposition of the large number of individual recordings, for example, in the manner of image pixels.

The produced video screen hologram is constructed as a contact hologram or as a so-called image plane hologram, in which the projected image when displayed appears in the hologram plane. By luminating screens in the primary colors red, green and blue into the same hologram layer 12 or into three layers laminated onto one another, colored images can later also be projected onto the holographic screen.

Contact holograms have the advantage of a simple optical construction during the recording. As illustrated in Figure 1, the hologram is therefore placed in contact onto the real video screen 11, for example, a reflecting scattering lens or transmitting obscured glass and is luminated together with the reference beam without any additional object illuminating. During the projection, the angle of the backscattered projection light from the hologram 12 in the direction of the viewer is the same as that of the real video screen with respect to the recording light beam 13.

The invention is based on the fact that the holographic video screen or the hologram 12 must reflect the optical

characteristics of the image pixels, that is, the brightness (half-tone), the color, the polarization and the angle of radiation only individually for each pixel from the screen. An optical linking between adjacent pixels does not exist, and a video screen as a contact or image plane hologram has only a two-dimensional structure. So that the hologram 12 can reflect this method of operation of a flat video screen in the hologram plane, it is not absolutely necessary [the] to record the real video screen 11 in a single lumination over an extended hologram surface, as takes place in the case of holograms of three-dimensional objects, but the video screen may be constructed as an assembled film or a film constructed in a mosaic-type of separate individual recordings of partial areas 11a of a video screen. These partial areas 11a may therefore be reduced to the size of an individual image pixel.

The holographic video screen is recorded by luminating the real larger video screen 11 with a rapidly pulsed laser beam 13 which is scanned without gaps over the entire surface. To ensure [So] that the movement of the beam 13 over the screen 11 or over the recording material 12 has no influence on the interference of the light waves in the hologram 12, [it is ensured that,] on the one hand, the pulse duration of the laser 16 is kept sufficiently short, and [that,] on the other hand, the coherence length of the laser light is sufficient [for the forming of] to

form the interferences. In order to achieve a particularly economical production of the holographic screen, the pulse repetition frequency of the laser 16 and its median power is sufficiently high so that a short luminating time is achieved.

Suitable lasers for this type of holographic lumination are, for example, high-power, rapidly pulsed, diode-pumped infrared solid-state continuous-wave lasers with only a single longitudinal mode whose radiation is displaced by frequency conversion into the red, green and blue wavelength range. The scanning of the video screen surface can take place by means of commercially available laser beam scanners.

The partial holograms 11a are selected at least [so] large enough that no disturbances occur, such as a reduction of contrast, [a] color distortion and [a] reduction of the image resolution in the later image reproduction by light diffraction or a fine structure of the holograms itself. Such disturbances are not expected if the partial holograms 11a are larger than the image pixels of the projection. On the other hand, the size and the shape of the partial hologram 11a and the scanning rate can be selected such that, by means of the defined operating parameters of the recording laser, such as the median power and the pulse repetition frequency, an optimal irradiation and a homogeneous illumination of the hologram 12 is achieved without

reducing the efficiency of the recording simultaneously by the movement of the scanning beam 13.

In general, for the recording of object holograms, the object itself must be illuminated by means of an object beam and the hologram must be illuminated by means of a reference beam. The light scattered by the object is then superimposed with the reference beam in the hologram film. [with respect to the reference beam.] In the case of the pulsed recording illustrated [here,] in which only a portion 11a of the real video screen 1 is illuminated as the object and simultaneously a portion of the hologram 12 is illuminated directly by means of the pulsed reference beam 13, the luminations are implemented in a synchronously superimposed manner. This can easily be implemented by means of contact holograms, in [the case of] which the hologram film 12 is placed directly on the real video screen 11 and the reference beam 13 is used both for illuminating the hologram 12 and for illuminating the video screen 11.

In the case of image plane holograms, the video screen is imaged by means of a lens into the hologram. So that the partial illumination of the video screen with the object beam and the hologram with the reference beam mutually overlap, the two scanning beams must be mutually synchronized during their movement, such that the imaged spot of the video screen in the

hologram and the spot of the reference beam will in each case be congruent.

During the lumination, the light waves in the object beam and the reference beam must be coherently imposed on one another in the hologram. This means that the coherence length of the used illumination laser 16 has to be at least as large as or larger than the difference of the light paths between the waves of the object beam and the reference beam which originate from a common beam, until they meet again in the hologram 12. Within the scope of the invention, this [demand] requirement can be met by a corresponding design of the beam guidance and the build-ups of the holograms with respect to the coherence length of the available lasers.

The movement of the interfering waves in the hologram by the scanning beams (object beam and reference beam) during the pulse duration, with respect to one another and with respect to the hologram film, amounts to no more than fractions of the wavelength ($<\lambda/10$). This condition is met by a corresponding adjustment of the scanning rate [in relationship to] corresponding to the pulse duration of the laser. In the case of a pulse duration of 10 ns and a scanning rate of 5 m/sec, the movement of the beam is, for example, 50 nm, which corresponds to approximately $\lambda/10$.

During the scanning with a pulsed radiation at a constant power from pulse to pulse, a large hologram surface can be covered with a uniform average intensity distribution. However, [, but] the lumination [,] (that is, the light intensity times the time), depending on the ratio of the scanning rate to the pulse repetition frequency of the beam with the Gaussian intensity profile, will be periodically modulated over the whole surface along the scanning sweep. The invention therefore also provides that this periodic local non-uniformity of the illumination as well as inhomogeneities in the hologram thickness, for example, in the case of a mosaic-type laying of several holograms side-by-side, are compensated by a repeated scanning of the same surface by means of a phase-shifted scanning beam or by controlling the pulsed power. Here, the invention partly utilizes the characteristic of hologram recordings that several object luminations can be stored in an overlapping manner and independently of one another in a single hologram.

So that this lumination process can take place automatically, in one embodiment of the invention (not shown), the distribution of the lumination is monitored by a calibrated backscatter sensor which is arranged in the beam path of the illumination laser coaxially to the pulsed lumination beam. As an alternative, monitoring cameras may continuously measure the

laser illumination over the entire hologram surface. The lumination pattern thus obtained can be stored by a microprocessor or computer, and can be used during subsequent repeated scanning cycles over the entire hologram surface by controlling the laser light intensity and surface distribution of the scanning figure for the subsequent correction of the lumination of the preceding lumination patterns.

After the development process, the optical characteristics of the video screen are stored in the hologram 12. Preferably, so-called thick holograms (10-20 μm) are used, for example, consisting of photopolymer, dichromate gelatin or silver halide materials. In comparison to thin holograms, thick holograms have the advantage that they particularly selectively diffract out light with the same wavelength as during the recording, specifically only when the angle of incidence of the reconstruction beam is the same as the angle of incidence of the reference beam during the recording.

The optimal accumulated lumination of the holograms differs for each material and for each wavelength. For photopolymer materials, for example, it is at approximately 25 mJ/cm^2 ; that is, for the lumination of 1 m^2 with a laser 1 W of median power, 250 seconds or approximately 4 minutes are required. In the case of silver halide films, a lumination of only approximately 0.5

mJ/cm², is necessary, so that the lumination time can be correspondingly shortened. Image plane holograms are recordings of screens imaged by means of lenses or mirrors, which screens are situated in the hologram plane. The angle of radiation of these holograms can be considerably narrowed by the imaging geometry, with a corresponding increase of the brightness of the image, which is very advantageous for many applications.

Figure 3 illustrates a recording of a contact hologram of a video screen 31 as a transmission hologram 32. In this case, it is necessary that a reference bundle of beams 33, whose beam path coincides with the projection beam during the later image reproduction, impinges as a convergent partial beam bundle of a pulsed laser 39 on the hologram 32. The interference structures which then form in the hologram 32 as the result of the superimposition of scattered light 30 from the screen on the reference bundle 33 of beams, will then correspond to an image reproduction in a rear projection from the intersection or projection point 36, that is, the lengthening of the beam bundle 33. During the projection, the viewer will then stand opposite the later projection point 36 on the opposite side of the hologram 12. The generating of a convergent bundle of beams from a two-axis scanner 34 and 35 can most easily be implemented by way of a mirror 37 of a long focal length which images the source point of the scanner 38 in the intersecting point 36. The

hologram 32 and the real video screen 31 are then placed in a sectional plane of the beam path of the partial beam bundle 33.

Figure 4 illustrates a recording of a transmission hologram as an image plane hologram for the rear projection. Here, a real video screen 41 is imaged by means of a lens 46 on a hologram 42. Simultaneously, a reference beam bundle 43 impinges from the other side on the hologram 42. The two scanners with the x-y scanner mirrors 47 and 48 or 47' and 48' are synchronized such that the two illumination spots of the reference beam bundle 43 and of the illuminated surface 40 of the real screen in the hologram 41 are synchronously superimposed. The illumination beams for the real screen 42 and for the reference bundle 43 of beams are separated and deflected by means of separator mirrors 44 and deflecting mirrors 44' from the common laser 49.

Figure 5 illustrates a recording of an image plane hologram as a reflection hologram for the later front projection. In this case, a real screen 51 is imaged in a hologram plane 52 by means [laying of several holograms side-by-side, are compensated by a repeated scanning of the same surface by means of a phase-shifted scanning beam or by controlling the pulsed power. Here, the invention partly utilizes the characteristic of hologram recordings that several object luminations can be stored in an overlapping manner and independently of one another in a single

hologram.

So that this lumination process can take place automatically, in an embodiment of the invention which is not shown, the distribution of the lumination is monitored by a calibrated backscatter sensor which is arranged in the beam path of the illumination laser coaxially to the pulsed lumination beam. As an alternative, monitoring cameras may continuously measure the laser illumination over the entire hologram surface. The thus obtained lumination pattern can be stored by a microprocessor or computer and can be used during subsequent repeated scanning cycles over the entire hologram surface by controlling the laser light intensity and surface distribution of the scanning figure for the subsequent correction of the lumination of the preceding lumination patterns.

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reference beam during the recording.

The optimal accumulated lumination of the holograms differs for each material and for each wavelength. For photopolymer materials, for example, it is at approximately 25 mJ/cm^2 ; that is, for the lumination of 1 m^2 with a laser 1 W of median power, 250 seconds or approximately 4 minutes are required. In the case of silver halide films, a lumination of only approximately 0.5 mJ/cm^2 , whereby the lumination time can be correspondingly shortened. Image plane holograms are recordings of screens imaged by means of lenses or mirrors, which screens are situated in the hologram plane. The angle of radiation of these holograms can be considerably narrowed by the imaging geometry, with a corresponding increase of the brightness of the image, which is very advantageous for many applications.

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reproduction in a rear projection from the intersection or projection point 36, that is, the lengthening of the beam bundle 33. During the projection, the viewer will then stand opposite the later projection point 36 on the opposite side of the hologram 12. The generating of a convergent bundle of beams from a two-axis scanner 34 and 35 can most easily be implemented by way of a mirror 37 of a long focal length which images the source point of the scanner 38 in the intersecting point 36. The hologram 32 and the real video screen 31 are then placed in a sectional plane of the beam path of the partial beam bundle 33.

Figure 4 illustrates a recording of a transmission hologram as an image plane hologram for the rear projection. Here, a real video screen 41 is imaged by means of a lens 46 on a hologram 42. Simultaneously, a reference beam bundle 43 impinges from the other side on the hologram 42. The two scanners with the x-y scanner mirrors 57 and 58 or 57' and 58' are synchronized such that the two illumination spots of the reference beam bundle 43 and of the illuminated surface 40 of the real screen in the hologram 41 are synchronously superimposed. The illumination beams for the real screen 42 and for the reference bundle 43 of beams are separated and deflected by means of separator mirrors 44 and deflecting mirrors 44' from the common laser 49.

Figure 5 illustrates a recording of an image plane hologram

as a reflection hologram for the later front projection. In this case, a real screen 51 is imaged in a hologram plane 52 by means] of a lens 56, and the image is synchronously superimposed there with a reference bundle 53 of beams. By means of a separator mirror 54, a portion of the reference bundle 53 of beams can be used for illuminating the real screen 51. Additional auxiliary mirrors are required for compensating the space reflection of the lens 56, which is illustrated here for the one space plane on the example of the auxiliary mirror 55. For the simultaneous scanning of the screen 51 and the hologram 52, only one pair of scanner mirrors 57 and 58 is used here in front of the pulsed laser 59.

In order to facilitate the recording of three-color or multicolor screens, for example, of the rgb colors, the beams of three rgb lasers or of one laser with a three-color rgb emission are coaxially adjusted with respect to an identical beam axis. During a joint scanning and luminating of the screen and of the hologram with the reference beam, the three colors are simultaneously on the real video screen. The reference beam also represents a superimposition of three rgb partial beams.

This simultaneous recording of all three rgb colors in the same hologram naturally requires that the hologram material is photosensitive to all colors. However, this also applies to a

number of photopolymers and silver halide films as well as to individual dichromate gelatins.

For recording the video screen holograms described here with a rapidly pulsed rgb illumination, modern diode-pumped, q-switched infrared solid-state lasers are used with an emission in only one longitudinal resonator mode. The lasers are adjusted to the rgb emission at the suitable rgb wavelengths by a classical frequency conversion, such as frequency doubling, optically parametric processes and summation and difference frequency formation, in various non-linear crystals.

Separate lasers can be used for the individual colors, but it is more advantageous to use lasers which have a single joint q-switched laser oscillator. The lasers [of] have joint amplifier stages on the output side and a joint optical-parametric oscillator which splits the fundamental wave of the laser or its frequency-doubling wave into two partial waves of a longer wavelength (idler and signal wave). A subsequent beam separation is used for separating the primary radiation into different beam branches, where different further frequency conversions take place, such as frequency doubling, frequency summation and difference formation for producing the individual colors.

A significant advantage of such a joint primary laser is the fact that the emission of all three rgb color branches takes place completely synchronously with the same pulse repetition frequency, in a solid phase and with a comparable spectral width, coherence length and beam divergence. This permits a joint recording of the video screen holograms simultaneously in all colors.

RGB lasers, which are based on this basic concept of a joint primary laser with a subsequent frequency conversion in passive non-linear crystals to the three rgb colors, are described, for example, in the above-mentioned German Patent Document DE 195 04 047, "Laser System for Color Image Projection", and in German Patent Document DE 44 32, 029, "Laser-Supported Color Image Display and Projection Device". The diode-pumped solid-state lasers described there are operated in the mode-locked continuous-wave mode. However, with respect to the recording of video screen holograms, they have the disadvantage that they emit a wide frequency spectrum of individual longitudinal modes, that is, of a short coherence length in the primary emission as well as after the frequency conversion.

Figure 6 illustrates a laser according to the invention which is particularly suitable for the above-described pulsed video screen hologram recordings. In this case, instead of a

mode-locked laser, a rapidly pulsed q-switched single-frequency IR oscillator 61 of an Nd laser, such as Nd:YLF, Nd:YAG or Nd:YVO, is provided; that is, the oscillator 61 has a single longitudinal mode. The power amplification of the pulses takes place in a solid-state laser amplifier 62 of the same materials. An optical parametric oscillator 65 is provided for [a] subsequent frequency splitting. This oscillator can be adjusted in its wavelength by way of the temperature of the non-linear material and/or the adjustment of the axis angle in the beam path. As a result, the wavelength of the effective rgb radiation can also be adjusted during the subsequent frequency conversion. This is advantageous for precisely adapting the recording wavelength to the later reproduction wavelength. A frequency doubling and summation frequency formation also takes place. [The oscillator 61, is a q-switched Nd:YAG in the longitudinal single-mode operation. The laser amplifier 62 is an Nd:YAG or Nd:YVO amplifier chain. Furthermore, a frequency doubler crystal 63 is provided as well as beam separators 64, 64' for separating the fundamental radiation of the primary laser $\lambda_1=1.06 \mu\text{m}$ from the frequency-doubled green radiation $\lambda_1=0.53 \mu\text{m}$. The optical parametric oscillator 65 is pumped by means of the green beam λ_1 and adjusted such that it generates two signal and idler beams (λ_s and λ_i respectively), which have a suitable wavelength for a subsequent summation frequency formation in summation frequency generators 66, 67. In this case, the wavelengths λ_s and λ_i are

selected such that the summation frequency formation with the beams of the fundamental wavelength of the laser $\lambda_1 = 1.06 \mu\text{m}$ (or $1.04 \mu\text{m}$), which remains after the frequency doubling, results in suitable wavelengths of red and blue. In contrast, the color green is taken over as part of the frequency-doubled radiation of the primary laser by way of splitting by the simple beam separator 64, 64'.

The suggested rapidly pulsed q-switched laser 61 is a continuous-wave laser oscillator with only one longitudinal fundamental mode which is operated in a pulsed operation of the resonator. A laser of this type is, for example, a diode-pumped solid-matter microchip laser, such as the Nd:YAG at a laser wavelength $1.06 \mu\text{m}$ with such a short resonator that it starts lasing only on a longitudinal mode. By means of an internal passive quality switch, for example, made from the known Cr^{4+} :YAG material, the resonator can be adjusted by the doping with Cr^{4+} ions, for example, to 20 kHz pulse frequency with a pulse duration of 10 ns.

The IR-emission of the laser 61 is now be highly amplified in the amplifier 62 which follows; for example, by means of the crystal Nd:YAG or Nd:YVO, by a factor 10-100, without creating interfering higher longitudinal modes, also while maintaining the good beaming quality of the oscillator. After the amplification,

the pulsed beam is then still frequency-doubled to the desired green wavelength 532 nm, which occurs here in a KTP crystal 63. After the frequency doubling, which takes place here with an efficiency of approximately 30%, a portion of the primary radiation with a wavelength of 1.06 μm remains for a further use in the subsequent stages.

A second possibility is the use of passively quality-switched Nd:YAG ring lasers with the same Cr^{4+} YAG quality switch, a similar pulse repetition frequency, but a better frequency stability and a higher median power. By means of subsequent amplifier stages as in the previous case, a median power of 10-39 W can be generated in a longitudinal mode.

One possibility is the use of a laser actively quality switched by means of an acoustic-optical switch with an internal standard for adjusting a single-mode operation, which, however, requires slightly higher expenditures in comparison to the second process.

Q-switched continuous-wave lasers of the type described here have a pulse repetition frequency of 10-20 kHz, a pulse width of 5-20 ns and a frequency bandwidth of the laser emission below 100 MHz. They can be designed such by means of an amplifier stage that, after the frequency doubling 1 W green emission is created,

and by means of two or three stages, up to 10 W green radiation is generated and 30 W infrared radiation is generated in the device. After the conversion in the optical parametric oscillator 65 and a further frequency doubling or summation frequency formation, all rgb beams can then be produced with a median power of several watt. A significant advantage of this concept is also that the colors blue and red can be continuously displaced by the adjustment of the wavelengths of the idler and signal wavelength λ_s , λ_i in the optical parametric oscillator 65 for the adaptation to the wavelength of the later image projection lasers.

By means of the characteristic laser data, such laser systems are particularly well suitable for the recording of the video screen holograms. If, for example, the pulse duration of the laser amounts to 10 ns and the scanning rate amounts to 5 m/sec, during this pulse duration, the beam moves laterally by 5×10^{-8} m during this pulse duration, which corresponds to 1/10 of the wavelength at, for example, 500 nm. This small displacement has no noticeable influence on the quality of the interference pattern in the hologram. If the pulse frequency were, for example, 20 kHz, the beam would move from pulse to pulse at this scanning rate by 1/4 mm. The coherence length of a $\Delta t = 10$ ns single-mode pulse amounts to approximately $\Delta t \cdot c = 3$ m, wherein c is the speed of light. The difference of the

travelling paths of the object and reference beam must] The oscillator 61, is a q-switched Nd:YAG in the longitudinal single-mode operation. The laser amplifier 62 is an Nd:YAG or Nd:YVO amplifier chain. Furthermore, a frequency doubler crystal 63 is provided as well as beam separators 64, 64' for separating the fundamental radiation of the primary laser $\lambda_1=1.06 \mu\text{m}$ from the frequency-doubled green radiation $\lambda_g=0.53 \mu\text{m}$. The optical parametric oscillator 65 is pumped by means of the green beam λ_g and adjusted such that it generates two signal and idler beams (λ_s and λ_i respectively), which have a suitable wavelength for a subsequent summation frequency formation in summation frequency generators 66, 67. In this case, the wavelengths λ_s and λ_i are selected such that the summation frequency formation with the beams of the fundamental wavelength of the laser $\lambda_1 = 1.06 \mu\text{m}$ (or $1.04 \mu\text{m}$), which remains after the frequency doubling, results in suitable wavelengths of red and blue. In contrast, the color green is taken over as part of the frequency-doubled radiation of the primary laser by way of splitting by the simple beam separator 64, 64'.

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A second possibility is the use of passively quality-switched Nd:YAG ring lasers with the same Cr⁴⁺ YAG quality switch, a similar pulse repetition frequency, but a better frequency stability and a higher median power. By means of subsequent amplifier stages as in the previous case, a median power of 10-39 W can be generated in a longitudinal mode.

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beam would move from pulse to pulse at this scanning rate by 1/4
mm. The coherence length of a $\Delta t = 10$ ns single-mode pulse
amounts to approximately $\Delta t c = 3$ m, wherein c is the speed of
light. The difference of the travelling paths of the object and
reference beam must not exceed this value, which can easily be
observed in the case of all suggested embodiments [build-ups] of
the holograms.

Therefore, video screen holograms can be designed either for
a front projection as a reflection hologram, or for a rear
projection as a transmission hologram. [Either the recording]
Recording in both the contact process with the real video screen
[, or] and as an image plane hologram[,] (that is, after an
imaging of the video screen on the hologram, as illustrated
above)[,] are suitable for both processes. In all cases, the
object beam and the reference beam are moved synchronously over
the hologram.

Only light sources with an identical linear polarization can interfere with one another and be stored as a holographic image of screens in a hologram; that is, only light waves of an identical linear polarization in the reference beam and the object beam can contribute to generating the image of the video screen. Therefore, the lasers used for the recording of the holograms are preferably polarized in a strictly linear manner in order to ensure the efficiency and the homogeneity of the illumination over the entire hologram surface. Since most lasers with a good beaming quality are strictly linearly polarized from the start, this does not cause any limitation of the recording technique.

For [the] recording of video screens for [the] stereoscopic image reproduction, video screen materials are used which depolarize an impinging linearly polarized light beam by backscattering or by forward scattering. This applies to many projection screen materials for the rear projection with a good fine roughness of the surface or a slight volume scattering, and to almost all projection screens with a high volume scattering for rear projections. Since the reference beam also has a strict polarization direction of the laser, when a real video screen is recorded, this polarization direction is maintained in the hologram. If now two recordings are successively made of the same screen, in which [case] the polarization direction of the

reference beam is rotated from one to the other by 90° , two independent screen images are created in the same video screen hologram, each being effective only with respect to a projection beam with a defined polarization direction. Both screen images affect mutually orthogonal polarized projection beams. Thus, also prerequisites are met for the projection of mutually orthogonally polarized stereo images and their stereoscopic viewing by means of polarization glasses.

The switch-over of the polarization by 90° in the reference beam can be carried out [in a] very [simple manner] simply by rotating a $\lambda/2$ -plate in the beam path behind the outlet aperture of a strictly linearly polarized illumination laser.

If several video screen recordings are made of the same screen successively into the same hologram while the site of the whole screen or of the place of origin of the reference beam are changed, the interfering speckle images are superimposed coherently with a statistical size distribution. Together, they represent a new virtual screen after the luminations, which screen has a significantly higher fine structure than the real original screen. This results in a displacement of the entire appearance image toward larger speckles which then, during the subsequent image reproduction, can be eliminated more easily by

a slight local or time-related modulation of the projection beams. Therefore [the characteristic] this technique utilizes the ability of holograms to store [is utilized of storing] several images with slightly changed recording condition above one another but independently of one another in the same hologram. Also in the case of video screen holograms which are recorded by means of pulsed lasers, the size of the interfering image speckles which occur during the image reproduction by means of lasers can therefore be changed.

The method described here of recording a scattering holographic video screen can also be used for recording the function of a plane mirror which basically represents only a borderline case of a scattering surface. Because of their selectivity in the wavelength, such holographic mirrors can advantageously be used as auxiliary elements in the recording devices or in the projectors.

The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.

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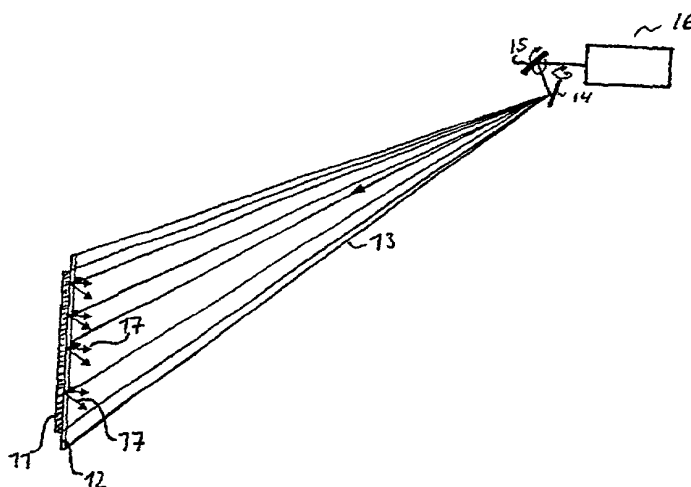
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[Fortsetzung auf der nächsten Seite]

(54) Title: METHOD, DEVICE AND LASER SYSTEM FOR PRODUCING SCREEN HOLOGRAMS, AND SCREEN HOLO-
GRAM

(54) Bezeichnung: VERFAHREN, VORRICHTUNG UND LASERSYSTEM ZUR HERSTELLUNG VON BILDSCHIRMHO-
LOGRAMMEN, SOWIE BILDSCHIRMHOLOGRAMM



(57) Abstract: The invention relates to a method for producing screen holograms in which a real screen (11) is illuminated with narrow-band light (13) in order to produce a hologram (12) of the real screen. To this end, a multitude of individual shootings is carried out, whereby only one partial area of the real screen is mapped in the hologram (12). The individual shootings are carried out, for example, using a scanning pulsed laser beam. The individual shootings assemble to form a screen hologram of the entire screen (11). A recording device comprises a scanning device for guiding the luminous radiation (13) over the screen (11) and comprises a light source (16) which generates the pulsed luminous radiation. The light source (16) is, for example, a laser system comprising a pulsed, q-switched oscillator and an optical parametric oscillator.

[Fortsetzung auf der nächsten Seite]

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DECLARATION AND POWER OF ATTORNEY

(For Use with Application Data Sheet)

As the below named inventor(s), I/we declare that:

This declaration is directed to:

The attached application, or
XX PCT Application No. PCT/DE00/02220, filed on 6 July 2000 (06.07.00)
__ as amended on __ (if applicable);

I/we believe that I/we am/are the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought;

I/we have reviewed and understand the contents of the above-identified application, including the claims, as amended by any amendment specifically referred to above;

I/we acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me/us to be material to patentability as defined in 37 CFR 1.56, including material information which became available between the filing date of the prior application and the National or PCT International filing date of the continuation-in-part application, if applicable;

I/we hereby appoint the practitioners at **CROWELL & MORING L.L.P.**, whose Customer Number is:



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as my/our attorneys to prosecute the application identified above, and to transact all business in the United States Patent and Trademark Office connected therewith; and

All statements made herein of my/our own knowledge are true; all statements made herein on information and belief are believed to be true, and further these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and may jeopardize the validity of the application or any patent issuing thereon.

FULL NAME(S) of INVENTOR(S)

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Date: February 7th 2002

__ Additional Inventors on Attached sheet if checked